WGLN Project Proposal

Internet Assisted Laboratories (I-Labs)

Principal Investigators

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Version 2.2, 26 March 2001

Executive Summary

The goal of this project is to:

1. Investigate how to optimally design and organize **distributed online laboratories** that allow: a) teams of students to remotely access laboratory devices and b) remote collaboration in performing experiments.
2. Implement two I-Labs using the optimized approach; a) one in physics at Stanford and b) one in mechatronic engineering at Hanover.
3. Evaluate the use of these distributed laboratories in teaching and training environments, including testing of usefulness of the distributed labs at the partner institution for application in teaching and training
4. Report the results at six months intervals at joint meetings

WGLN Funding

This project proposal covers at least two years or research and evaluation with a total request for **WGLN funds of $350’000 per year**. The I-Labs Physics part at **Stanford (SLL)** requests **$175’000** and the I-Labs Mechatronics at **Hanover (L3S)** request **$175’000**. From the Hanover part $35’000 are kept for collaboration with the Global Learning Teams project.

Research Agenda

The effort comprises of three major topics:

1. Extension of the core Cyberlab technology (Stanford) for remote control and collaboration and the remote lab technology (Hanover) for control, organization and management of online laboratories. Exchange and migration of tools from both technologies, if promising and appropriate.
2. Development of two test beds.

a) A small scale, integrated opto-mechanical laboratory at Stanford University to instigate the following question: How small can an I-Lab be made while still maintaining all necessary educational requirements and realizing the enormous benefits of reduced cost and size?

b) A lab at Hanover focused on remote control of mechatronic experiments, combined with simulations and team cooperation to improve the efficiency of the learning process.

3. To investigate critical questions:

a) What new strategies are required for cooperative learning in distributed labs?

b) What new learning environments are available and useful to enhance sensory perception in an I-Lab environment, including smell, tactile senses and 3-D perception?

c) How to optimize the design and use of the physical and virtual spaces required for I-Labs?

d) How to design the flexibility of I-Labs for use among disparate heterogeneous learning constituencies and within alternative learning scenarios?

e) How to fulfill safety, security, and reliability constraints of remote device control?

f) What is the role and usability of simulation methods in conjunction with I-Labs?

These questions will be answered by our research with respect to the educational objective: How do we best teach students to learn to think?

Research Outcomes

- Two well defined test programs, professionally evaluated for teaching and learning effectiveness.
- Detailed knowledge about how to optimize the learning and cost effectiveness of online labs.
- Prototypes and working examples of two specific I-Labs.
- Selected I-Lab tools (toolbox) that prove useful for education and learning purposes, which may possibly be transferred to other areas (e.g. medicine, chemistry or mechanical engineering).

Rationale

Online labs are important in several learning situations. The first of these is the distance learning scenario. In this situation, learners execute a laboratory-oriented course or exercise from their homes or places of employment. Individual learners are remote from each other so that *collaboration is distributed.* A recent poll of university administrators in the United States showed distance learning to be among the top issues in terms of importance. Once languishing in the backwaters of academic life, distance learning has been pushed to center stage by the growth of the Internet and the demand for life-long learning. There are currently an increasingly large number of efforts to provide the online analog of the university classroom. However, there are comparatively few efforts to provide the online analog of the university laboratory, as lectures are simpler to implement in the Internet environment. Yet, laboratory learning is a key part of a well designed curriculum. As the numbers of distance learners and distance learning programs increase, the demand for online laboratory experiences will also increase.

The second important scenario for online labs is the ed-to-ed application. In this situation, learners at one educational institution execute a laboratory course or exercise hosted by a second institution. Although remote from the lab, the learners are collocated with each other so that collaboration is local. This offers the opportunity for universities, departments, or individual instructors to maintain and execute experiments in laboratory environments that are too costly, too time consuming, or too difficult to maintain and execute individually. This could for example, make available to a community college or trade school laboratory-based learning experiences that traditionally have been possible only at research universities.

A final scenario of interest is integration of reality into live lectures and seminars. In this situation, learners observe a live (but remote) experiment or demonstration controlled by the instructor. In this scenario, the lab is brought online to the classroom.

Economic, space, and cost issues are extremely important and must be considered in any distance as well as conventional learning environment. I-Labs hold promise of being up to two orders of magnitude cheaper than conventional laboratories. The question is: How can we best design these new labs, use them optimally, and evaluate how well they perform in a distance learning and lecture room environment?

The Wallenberg Global Learning Network (WGLN) seeks to provide expertise and technical resources to formulate and solve the complex problems of global learning. The I-Labs project supports this vision by making it possible for institutions remotely located from each other to share resources leading to significantly reduced cost and by providing wider access to the specialized expertise and equipments needed for experiment-based learning and training. It also makes it possible for students remotely located from each other to participate together in collaborative learning experiences involving experimentation with laboratory equipment.

Types of Laboratories

Laboratory exercises are part of many university educational programs. Based on computers and the Internet we come to new types of laboratories which offer greater flexibility and allow access by more students within a given time frame while reducing the total acquisition, operating and maintenance costs.

Local Labs

The traditional way of doing experimental or constructive exercises is to go to a university's laboratory. Within that local lab you work in teams with tutorial help from teachers.

Engineering education should combine theory and practice. The feeling that students obtain by sitting in the laboratory will not be provided by simulations or remote access. Local labs are still the best way to get a first hands-on experience in operating laboratory devices. That's why Aktan and others have named their remote control engineering environment "Second Best to Being There (SBBT)"[1].

Virtual Labs

Virtual labs are software simulations of physical devices (e.g. measurement instruments) or other real life systems (e.g. economic systems). Computer animation and visualization can help to illustrate complex relationships during classroom teaching as well as in individual learning at home.

It is very expensive and time consuming to implement simulations which come close to reality, because you need to take account of far too many parameters and dependencies. If the behavior of the real system cannot be formalized by mathematical functions or precise rules, a simulation can by used to show general principles only.

Simulations are artificial and do not represent reality. If the lab experiment needs to show very specific effects, one has to use local or online labs.

Online Labs

In our definition, online laboratories do offer remote access to laboratory equipment, workbenches and all types of experiments via the Internet.

Online labs try to combine the prerequisites of local labs with the flexibility of simulations. Additionally online experimentation will develop engineering skills like remote

[1] Aktan, B.; Bohus, C.A.; Crowl, L.A. and Shor, M.H.: Distance Learning Applied to Control Engineering Laboratories. IEEE Transactions on Education, Vol. 39, No. 3, August 1996.

operation, diagnosis and maintenance, which could be important for the students in the near future.

Because of limited perception, (computer screen) the students in an online team have to plan and operate more carefully the lab experiments than the local teams. Therefore, online labs could possibly be used to teach planning and analyzing competencies in a more effective and inherent way.

We expect that most students will accept online lab experimenting and understand that net-based forms of learning have several advantages in comparison to present teaching. As with most new ways of teaching and learning, a student's motivation will possibly be increased at first.

Educational Conception

Early computer-based learning systems followed a behaviouristic theory of learning that regards learning as a passive alteration of the individual. In this process, the organism of the individual is only an intervening variable in the stimulus-and-response model.

Cognitive learning theories, take learning to be a structured cerebral activity. The individual, however, doesn't only use his head. Learning could be explained as the result of active contacts to nature and society. Additionally, learning theories based on performance theories see learning as a deliberately planned process of action.

In contrast to current purely receptive uses of the Internet for obtaining information, in a distance-learning experiment the Internet becomes a constructivist medium where knowledge is build up by the student in the learning situation (learning by doing). On the condition that the experiments include exercises with a high degree of interactivity real learning spaces are formed. Examples of these lab exercises are the graphical design and construction of programs or the planning and conducting of a systematic sequence of measurements.

The notion of learning behind the conception of our internet assisted laboratories approach is based on the model of the reflexive subject[2]. In line with the constructivist paradigm, students dealing with the teaching and learning environment are confronted with a demanding experiment or problematic situation (process engineering plant with a technical fault). The distance-learning experiment creates for the learner a greater proximity to reality due to its concreteness as an object, which is inherent in the system, in contrast to pure software simulation. This concreteness also serves to greatly increase the learners' motivation, since they see directly the physical effects of their actions and they are given responsibility for a materially represented process.

TABLE I
EVALUATION QUESTIONS ON DIFFERENT EVALUATION LEVELS[3]

Evaluation level	Central evaluation question
E1: product level	What result do experts arrive at on evaluating the program?
E2: reaction level	How do learners react to the program?
E3: learning level	What learning successes were achieved?
E4: action level	Could the learning content be transferred?
E5: success level	What effect did the learning unit have?
E6: return-on-investment level	How should one judge the investment in distance education?

Evaluation

We intend to provide information as to the suitability of distance-learning experiments in engineering education by a summary evaluation. The results will allow us to discuss questions such as, whether distance-learning experiments in contrast to pure simulations or

[2] Smith, K.A. and Waller, A.A.: "New Paradigms for Engineering Education"; FIE Conference, 1997, Pittsburgh, Pennsylvania

[3] Latchman, H. A.: "Salzmann, Ch.; Gillet, Denis: „Information Technology Enhanced Learning in Distance and Conventional Education"; IEEE Transactions on Education, Vol. 42, No. 4; November 1999; Seite 247-254.

other computer-based learning arrangements are more suited to the promotion of engineering competence.

Based on Kirkpatrick's levels approach[5], we have six levels of evaluation (see Table I) which feed into a needs analysis.

Evaluation approach

As success in learning is dependent both on situational as well as constituted parameters, the intention is to carry out the evaluation of the distance-learning experiments using a theory-based holistic approach. UCIT (Universal Constructive Instructional Theory)[6], developed since 1991, provides a suitable, subtle and systematic theoretical framework. According to UCIT, the teaching and learning system is divided into four components (learner, learning task, learning environment and reference framework) and three processes (knowledge use, knowledge acquisition and knowledge storage).

Within the evaluation, suitable methods are used to examine the learning requirements with respect to the professional, method and social competencies of the learners. In addition to this, it documents their motivation and acceptance with regard to the distance-learning experiment.

The evaluation of the component "learning task" is supported by its future and present significance, the exemplary nature of the topic and the question of whether the topic contributes to structuring in terms of content. Also, problematic aspects of the topic with regard to different learning groups need to be evaluated. After each of the distance-learning experiments have been carried out, we need to check what extent the learning objectives formulated within the methodological planning of the teaching/learning unit have been reached. It should also be related to the tests of prior knowledge carried out at the beginning.

The evaluation of the learning environment relates to the entire instruction process and has an influence on the instructional design of our online lab teaching/learning environments. By instructional design we mean the entire process of designing the learning environment. Evaluation of the learning environment thus takes place on the visual, content and structural level.

Evaluation methods

A suitable way of evaluating a distance-learning experiment is a comparative investigation of the process which varies of the reference framework. Three scenarios are conceivable (see Table II).

TABLE II
TEAM LEARNING TEST BEDS

Test Bed One	Test Bed Two	Test Bed Three
Test bed one is a conventional scenario of a laboratory experiment. Tutor, learners and the test object (experimental devices) are in one room. Although the technological basis is identical with test beds 2 and 3 (the process is controlled via an Internet connection), learners can see the result of their actions directly in front of them.	In contrast to test bed one, the learners are now in a different room, at a distance to the actual object. They receive visual impressions by a video transmission as well as some software tools (images of lab device states, graphic visualization). Tutorial supervision is direct here too.	The idea is altered here to the extent that the groups, the experiment and the tutorial supervision are spread out over different rooms which could be at distance locations (dorms, computer pools, mobile learners with notebooks and wireless LAN access etc.)

[4] Latchman, H. A.: "Salzmann, Ch.; Gillet, Denis: „Information Technology Enhanced Learning in Distance and Conventional Education"; IEEE Transactions on Education, Vol. 42, No. 4; November 1999; Seite 247-254.

[5] Kirkpatrick, D.L.: "Evaluating Training Programs. The Four Levels"; Berrett-Koehler; San Francisco 1994.

6 Schott, F.; Kemter, S.; Seidl, P.: "Theoretical aspects of instruction of multimedia learning environments"; In L. Issing & P. Klimsa (Hrsg.); "Information und Lernen mit Multimedia"; Psychologie Verlags Union; Weinheim 1997; Seite 179-192.

The network-based infrastructure enables analysis methods which are not possible in conventional teaching/learning arrangements. Thus synchronic recording of the learners and their activities in the teaching and learning environment, database-based "tracking" or "screen capturing" will possible allow us to obtain information on the learning strategies of the learners. Because of the amount of data we expect to collect this way we will need to develop new digital analysis procedures.

For main evaluation of our distance-learning experiments we will develop online questionnaires. They will be divided into the categories "existing knowledge", "preparation", "lab taking" and "transfer". The online questionnaires have to be filled in by the students at the beginning and immediate after finishing the lab exercises. The type of possible answers will include simple yes/no, multiple choice, grading and free text.

I-Lab Modules

The following modules constitute the research project as a whole:

I-Labs Physics (PI Lambertus Hesselink, Dale Harris collaborator)

Apply Cyberlab core control, collaboration and analysis technology to a microscopic optics, thermodynamics and telecommunication laboratory. The telecommunications lab will be used in support of a course on the subject taught by Professor Harris, and focuses on performance measurements.

FIGURE. 1
I-LAB PHYSICS PROTOTYPE (CYBERLAB).

The physics laboratories focus on experimentation with Boyle's Law, and grating optics and interferometry.

Initially, off-the-shelf micro electrical and mechanical systems such as pumps and motors will be incorporated into an integrated system having the same functionality as a larger, traditional laboratory already in existence. A demonstration program will be created and included in Physics I, Introduction to Physics. Currently, this course is digitized and provided to students via Stanford Online. An experiment-based problem will be presented to students in the class. They will be required to write programs to control the experiment, collect the data, and compare the results with theoretical calculations covered in class.

A professional assessment of the educational value of the remote lab will be done. Based on the results, future developments will be determined. The tools developed will be capable of handling a wide variety of experiments via remote control over the Internet.

The tools will be generic and may be applied to labs in physics, engineering, biology, chemistry, economics, geology, and medicine.

The overall goal is to extend the existing Cyberlab technology to include tiny devices. The challenge is to determine how to scale the experiment down in physical size while still maintaining the desired properties for use in distributed online teaching and learning. The motivation is the reduction in cost of an online lab while still providing a meaningful collaborative learning experience for participating students.

I-Labs Mechatronics (PI Bernardo Wagner)

Purely instructional sequences based on a course of lectures (e.g. the learning materials in our course "Design of Discrete Controllers") will alternate with example sequences based on exercises. Together with a problem statement and the actual distance-learning experiment as well as metacognitive sequences they will form the pedagogical articulation scheme of a complete action.

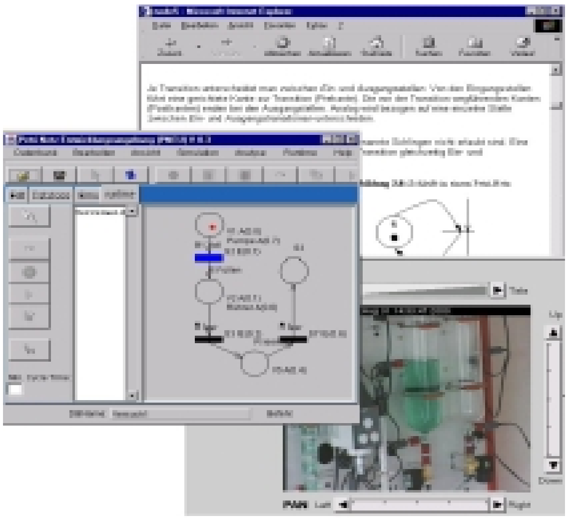

FIGURE. 2
I-LAB MECHATRONICS PROTOTYPE.

Based on conventional technologies (HTML, Java etc.), it is thus possible to observe and control our distance-learning experiments from the institute as well as from anywhere in the world. In our online lab (see prototype version in Figure 2) the laboratory devices can be observed through one or two web cameras and can be operated by a remote controller connected to the Internet. The control program is designed, implemented and tested interactively by small teams during the lab exercises. To do that they use a graphical editor (e.g. Petri net) and some other software tools which were developed at our institute. All tools will be programmed in Java. The necessary information regarding the lab experiment (theoretical background, user manuals, etc.) is provided on web pages using a Web-CT server.

We will implement and evaluate a collaborative distance-learning experiment as part of a control laboratory used in engineering education. Focus will be on use of conventional web-based technologies that make it possible to control and observe the experiment collaboratively from anywhere in the world. Existing remote lab technology from previous online lab projects in Hanover will be improved and completed.

To improve learning it is intended to involve learners in complete and purposeful projects and experiments. Additionally, this will be intensified by group learning and pre-structured problem-based learning. Starting with a motivating problem statement, students search out relevant material, plan and organize their work, and perform their planned work-packages. They verify, evaluate, present, and discuss their work among themselves.

Central evaluation questions will be: How do learners react to the online lab experience? What was learned? Was the learning transferable to the job or other life activities? What effect did the learning have? What was the return on investment? Network based infrastructure will be used to facilitate the evaluation. This will include synchronous recording of the learners and their activities, database tracking, and screen capturing. These tools will facilitate study of the learning strategies used as well as production of evaluation data.

Project Collaboration

The project partners at Stanford and Hanover will collaborate as close as possible. Four areas of cooperation have been identified:

- Regular live meetings, alternately in Stanford and in Hanover.
- Evaluation of students and faculty at both Universities.
- Joint technology development. Exchange of software tools and libraries.
- Exchange of students during Ph.D. study or master thesis.

Collaboration with other WGLN Projects

This project is related to both **the Interactive Space** and **Innovative Curriculum** initiatives. We have identified three WGLN projects which work on research topics interesting for the development and application of I-Labs. They are Mobile Learner, iSpace and VASE.

Online labs require the development of three types of physical spaces integrated into a single virtual learning space. The three physical spaces are:

1. the location of the physical laboratory equipment,
2. the location for groups of remote learners to congregate, access and control the laboratory equipment, and in general

collaborate with each other within a problem-based learning experience, and

3. the location of individual students participating in a collaborative problem-based learning experience from home or work. Each of these spaces requires careful and innovative design, as does the overall virtual space that integrates them all together.

The **iSpace** project treats with the development and implementation of newly interactive learning spaces. Results on this project will have impact on the design of I-Labs. Particularly we hope that within iSpace tools will be developed to overcome the existing problem of limited perception within online labs.

The proposed WGLN project "**I am here! Mobile Learners in dSpace**" mainly addresses the situation with learners being distributed and potentially mobile. Learners may want to access labs while travelling, sitting in a park or during sleepless nights in the dorm. Some of the deliverables of this project will be interesting to the I-Labs project (e.g. software distribution for ready-to-go personal environments based on notebooks, prototypes of mobility-enhanced devices and of a group-aware conferencing application).

To get students better prepared for laboratory experiments we have the idea to use simulations, which students can run without online access and security and safety problems. Therefore the **VASE** project (Visualization and Simulation Environments to Solve Difficult Learning Situations) will possibly be interesting to the I-Labs project. It concentrates on different aspects of virtual laboratories.

Online labs also require the development of innovative curriculum to optimize learning effectiveness within the online environment. In summary, the online labs environment is defined by the physical and virtual spaces involved and the curricular designs used.

Transfer to other Areas

Work on the I-Labs will start with experiments within the education of engineers. Nevertheless it is possible and necessary to bring online lab technology and educational methods to other areas. From previous talks to other WGLN institutions we know about the interest to use online labs in the following areas:

- Medicine (KI Stockholm)
- Telecommunication (EE Stanford)
- Heat and Power Technology (KTH Stockholm)

Additional WGLN test beds for online labs could come from these areas. Others educational departments like chemistry, mechanical engineering, biology etc. will follow afterwards.

Administrative Information

Location and Coordination of Distributed Activities

Work will be done at Stanford and Hanover Universities. The project will be coordinated from Stanford and Hanover with frequent video conferencing and occasional face-to-face meetings.

Time-Lines

Project start at Hanover: April 1st, 2001

Project start at Stanford: June 1st, 2001

End date for proposed work at all sites: August 30th, 2003

It is intended to continue our collaborative I-Labs project in a third year after successful evaluation and review of the delivered project results with a special focus on transferring the results to other areas (e.g. medicine). We know that this needs a new WGLN project proposal with additional partners.

Budget Table

- **L3S/Hanover:** 175 K USD for first and second year. Budget will pay for three Ph.D. students. One remote control expert (100%), one expert on computer supported cooperative learning (100%) and one expert on design and media education (50%). Budget includes overhead costs for travelling, exchange and infrastructure.
- **SLL/Stanford:** 175 K USD for first and second year. Budget will pay for two

Ph.D students, one for Professor Hesselink and one for the summer for Professor Dale Harris. It will also cover 10% of Prof. Hesselink's salary, and 3% of Dale Harris. The budget includes coverage for travel expenses, some support equipment, and student exchanges, as well as partial support for an expert in education.

Ongoing Relevant Research Participation

- SEPN - Control Design with Petri-Nets (funded by the ministry of Lower Saxony); Bernardo Wagner
- VOS - Virtual Control Laboratory (funded by the Unversity of Hannover); Bernardo Wagner
- Cyberlab (funded by Stanford University); Bert Hesselink