CyberLab: Remote access to laboratories through the world-wide-web

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Introduction

The world-wide-web has revolutionized the way in which information is disseminated. This has led to new paradigms for commerce, entertainment, and the way in which the physical world can be experienced. Over 20 years ago, Stanford University introduced a new concept to learning: the use of video for distribution and broadcast of classroom lectures[Ref 1]. In the last few years, video broadcasting and the web have been merged, and classroom lectures are now available over the Internet, to students anywhere, anytime. The classroom setting has been globalized.

An important educational element is still missing, however. A time-honored tradition in physics, biology, chemistry and engineering has been to augment classroom lectures with laboratory courses and live demonstrations in class. The lack of this capability has made some teachers in the physical sciences doubtful about the full potential of web-based education. The critical element of testing theories through experiments is missing. Until this issue is addressed, learning via the Internet cannot provide education that is as rich and all encompassing as a classroom lecture can be.

The missing link is the ability to carry out physical experiments over the web, fully integrated with other media for delivering classroom content, worldwide. In addition to simulating a virtual experiment, the reality of science and engineering can be learned better by remotely controlling an actual physical experiment. By supplementing classroom teaching with web-based experiments, the student should be able to interact with physical systems, much in the same manner as modern experiments are carried out today, under computer control. Laboratories accessible from the Internet provide enrichment to the educational experience that is hard to obtain from other video based remote teaching methodologies.

Remote control of experiments and equipment over the web is an idea that is just being explored. Tools are now becoming available for remote control of instrumentation using network communication. And several demonstrations of camera control and data acquisition as well as simple experiments have been made (Ref 2 and 3). To the best of our knowledge, however, no previous study has been reported in which extensive instrumentation can be controlled over the web, using an approach in which a plurality of educational tools is being integrated. The unique aspect of the current work is 1) our approach to develop a comprehensive, creative and novel learning environment to create a new paradigm in education and learning (CyberLab), and 2) the assessment of its educational value by researchers at the School of Education. These researchers have conducted an independent professional evaluation of the first CyberLab experiments at Stanford University, performed in the Fall of 1998.

Web-based experiments using CyberLab

Web-based learning extends beyond the confines of the classroom. Not only is delivery of educational content uncoupled from classroom schedules and locations, a new paradigm in learning, education and training is heralded. By controlling an actual experiment students can gain an understanding and experience beyond that which the classroom offers. On-line experiments allow direct control of

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physical processes and observation of noise and practical limitations. Only by observing real physical processes in their non-ideal conditions, students can gain a deeper physical intuition.

By sharing resources of facilities and personnel, the net cost per lab can be significantly reduced. The flexibility of scheduling and the worldwide access allow each remote laboratory to be used on a 24 hours a day basis. This contributes additional efficiency when compared to traditional laboratories in which dedicated resources are usually only available to students for a few hours each week. In addition to efficiency, flexible scheduling also allows students to perform the lab according to their individual schedules. Clearly by pooling resources, students at all levels can have access to expensive equipment, processes, and ideas worldwide. CyberLab lends itself particularly well to collaboration between educational institutions.

It is our vision, that by using a single facility to serve multiple institutions, efficiency and organization can be improved. Rather than designing a lab according to a single Professor or a single University, a shared lab can be better designed through collaboration of educators, scientists, and specialists. By serving many institutions and receiving more feedback data, laboratory procedures and content can also be continuously improved within a shorter time frame. The sharing of online facilities opens new possibilities in designing, refining, and evaluating (web-based) laboratories.

In addition to scientific understanding, laboratory experiments also give students experience in working together as a team. On-line experiments can be designed to allow collaboration and communication between multiple users in performing the experiment. The global access of the Internet allows collaboration to extend beyond a single location. This provides a new meaning to collaboration and allows students to share knowledge and exchange perspectives between institutions and across continents.

On-line laboratories offer the ability to remotely and independently observe students' progress without interfering with their learning process. Data can be collected in an unobtrusive manner concerning approach, planning, data collection, evaluation, and execution of laboratory experiments. These data provide a potential wealth of information about the learning process, the operation of equipment, and methods used to tackle problems.

In addition to the experiments, web-based learning provides a means for teaching students good educational methodology, laboratory practice, and safety procedures. Unlike a conventional lab, restrictions and policies can be systematically implemented which follow the proper structure for education. For example, in CyberLab a student is required to read the lab manual and successfully complete a pre-experiment test before being allowed to perform the lab. This insures adequate preparation on the students' part before taking the laboratory, a step frequently omitted in a traditional student laboratory environment. CyberLab also allows the actions students take regarding safety to be easily monitored and provides a means for feedback to the students on proper safety procedures to be followed (as an educational tool for hands-on experiments outside CyberLab) There are also an enormous number of specialized pieces of equipment in National Laboratories, corporations, Universities, high-schools and private laboratories that can potentially be made available to a broad spectrum of students and users everywhere. These devices and systems could be added to a worldwide network of CyberLabs, providing students opportunities for developing intuition and understanding far beyond the horizon of most students today.

The Stanford pilot study

At Stanford University a pilot study was begun with the following objectives: a) to develop a framework for integration of web-based classroom instruction and remote control of laboratory experiments; b) to implement a pilot program; c) to professionally and independently evaluate the performance and usefulness of the pilot program within the context of University learning; d) to explore new possibilities for improving classical classroom education. This vision of a remote laboratory is graphically represented by Figure 1.

Although we have chosen an optical experiment in this pilot program, the concept of CyberLab lends itself for experimentation in almost any field, including but not limited to mechanical engineering, aeronautics, electrical engineering, physics, biology, chemistry, medicine, material science and earth sciences.

Approach:

A functional web-based laboratory environment was created based on familiar concepts, having two primary sections: one public and one private. In the public section, information can be obtained about the philosophy of the CyberLab design, a description of the experimental capabilities, and an observatory. The observatory offers outsiders live observation of the laboratory and the experiments as they are executed. Inside the private section of CyberLab, a fully functional laboratory is present. The lab interface is designed with organization in mind that will teach good habits and etiquette. Thus in addition to the basic control of the physical experiments, the CyberLab interface also provides a lab scheduler, a reference library, course material, computer based analysis tools, testing facilities, and a lab notebook, shown in Figure 2.

Figure 1. The CyberLab perspective (artwork by Donny Effrien)

Lab Notebook

The lab notebook, shown in Figure 3 is the key concept around which the laboratory is designed. It provides the classical functions of data recording and note taking, but far extends beyond the traditional paper version. It provides a central repository of data describing the student's progress in the laboratory, the results of tests, data obtained during the course of the experiment, correspondence with the teachers and assistants, as well as a complete history of all steps taken by the student. The notebook functions as the medium by which teachers can evaluate the students' performance, and most importantly as a tool for organizing and managing laboratory information.

Students are required to study the material and take a pre-experiment test to qualify for using the equipment, and carry out experiments. In the conventional lab setting, students frequently conduct labs and operate equipment without having sufficient knowledge or understanding of the experiment and instrumentation. This commonly results in damaged equipment, safety hazards, and a lessening of the learning experience. By requiring students to follow a given procedure and achieving a certain performance standard on the pre-experiment test, CyberLab can ensure that students are well prepared before they begin the experiment. Textbooks and other reference sources are available on-line to provide resources for preparation. Upon passing the test, the student can schedule laboratory sessions to suit his/her preference.

The notebook also contains a “To Do List”, which serves as a status checklist that records steps already taken, informs what to do next, and provides a clear organization of the proper experimental procedure. This list includes the following elements: experimental description, safety procedures, equipment manuals, laboratory pre-experiment tests, scheduling, the physical experiment, analysis procedures, and a feedback questionnaire. By using the links within this list, students can easily navigate through each of the components of CyberLab.

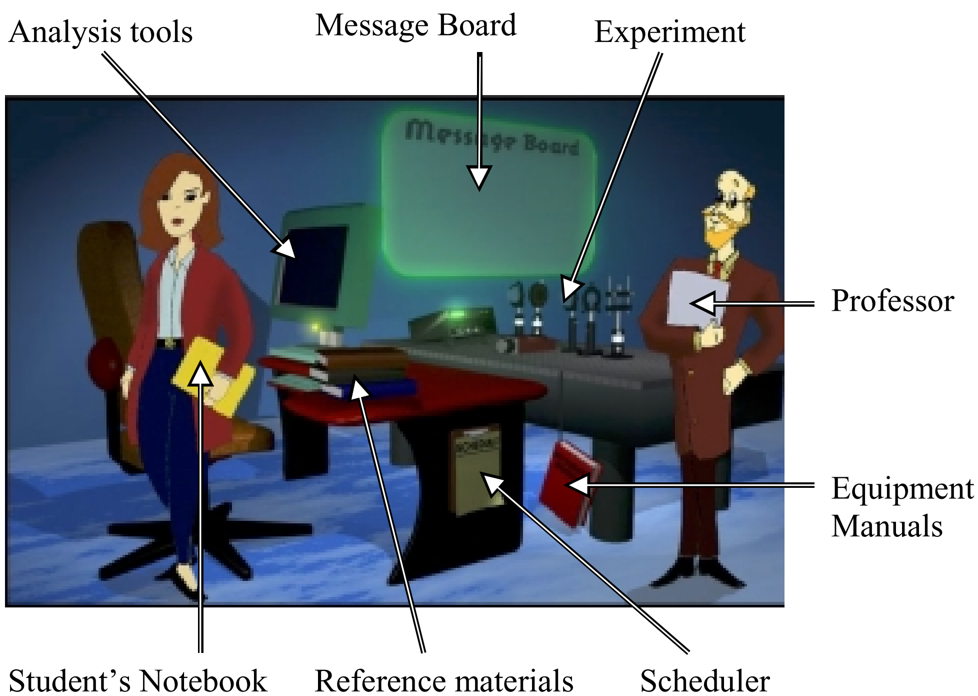

Figure 2. The laboratory Environment (artwork by Donny Effrien)

Experiment:

The laboratory experiment is controlled using web-based software modules. As a pilot program we have implemented an optical processor, shown in Figure 4. Collimated light is incident on an object. The transmitted light is Fourier transformed by a convex lens, and spatially filtered in the back focal plane of the lens. A second lens performs another Fourier transform which images the filtered object on the CCD camera. By mounting several objects on a motorized translation stage, remote control of the motor allows different objects to be selected and placed in the path of the laser beam. A second stage is similarly used to allow selection and precise remote alignment of filters within the Fourier plane. By mounting two lenses on a rotation stage, the operation of the second lens may be selected between Fourier transformation and imaging. As a result, the student can observe either the image of the filtered object or the object’s frequency spectrum.

Figure 3. The CyberLab notebook; the heart of the new paradigm in remote learning

In addition to being able to optically perform a Fourier Transform, students are also given the option of observing the Fourier transform computationally using the Fast Fourier Transform (FFT) algorithm [Ref 4]. By comparing the results of the optical Fourier Transform to those calculated from the FFT, students can confirm the expected transformation performed by the optics. Thus by performing the Fourier Transformation by two different techniques, students' understanding of this process can be extended beyond mathematical analysis of an equation. Hence the understanding gain through performing this lab will enhance their physical and scientific intuition.

Another aspect to be learned through laboratory experiments is how non-idealities in physical processes affect practical systems. Discrepancies between the theoretical results and observed experimental data are caused by noise in the system as well as random and systematic errors in the placement of components and their non-ideal performance. The student faces the intellectual challenge to understand the origin of the discrepancies, to provide a reasoned explanation for their occurrence, and to devise methods to enhance analysis. Thus by taking data from a real experiment rather than an ideal simulation, students gain experience in applying the theory learned in class to real applications.

The results of the experiment can be recorded in a notebook for future reference, including the state of the experiment at any given time. In addition, personal notes and comments can also be entered just as one would record in an actual notebook. Once data are recorded, they cannot be altered anymore in the notebook. This teaches the proper discipline in recording lab notes while performing an experiment. Experimental data can be downloaded for later analysis and report writing. The data is available in multiple standard formats to allow processing to be performed using many analysis tools.

Evaluation of CyberLab by the School of Education at Stanford University

A "needs assessment" study was conducted during October and November of 1998. Meetings and interviews with key participants, including the Principal Investigator and members of the CyberLab team were conducted in order to identify and outline the goals of the remote laboratory environment, to compose questions regarding the usability of CyberLab, and to identify potential problem areas of the program. The plan of action emphasized evaluation methods and instruments based on the data obtained from the needs assessment study. The primary methods and instruments chosen were surveys, observations, interviews, and the use of focus groups. The evaluation tools were designed to anonymously assess the goals of the program beginning with the pilot test in the Fall Quarter of 1998 and follow-on tests will continue through the Spring Quarter of 1999. The pilot test in the Fall Quarter of 1998 and the resulting data are used to further improve the evaluation process to be used for the Winter and Spring Quarters.

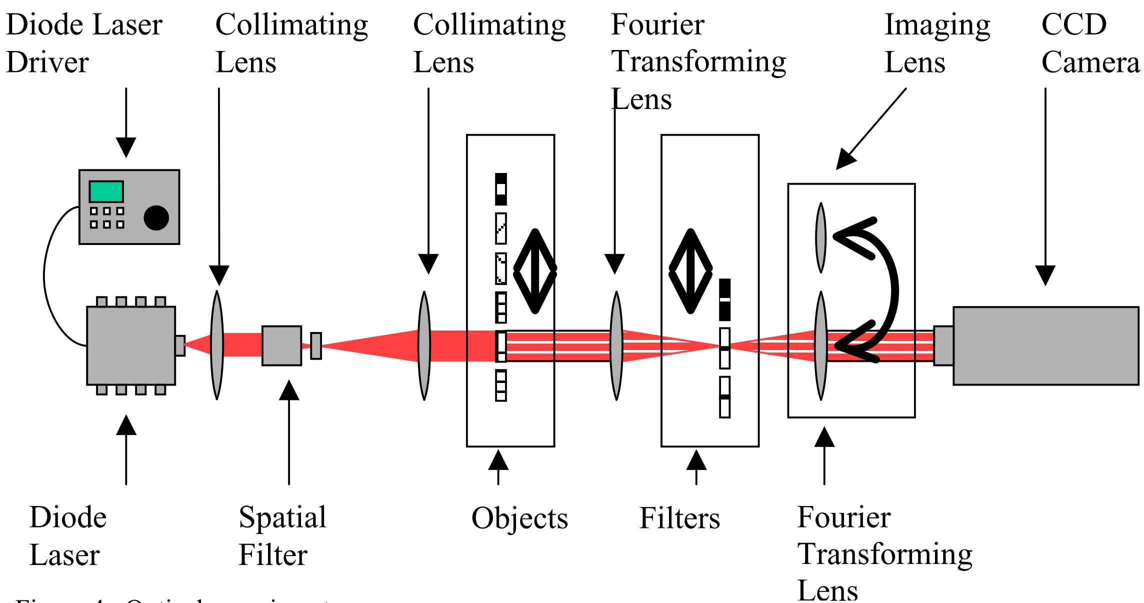

Figure 4. Optical experiment

Survey data obtained during the pilot test phase in the Fall Quarter of 1998 focused on gathering data for formatively improving the quality of the program. The survey was based on a four point additive scale. 15 students participated in the test program. The survey response rate was 73.3%. One issue with the survey response reliability arose from the integration of the survey into the remote laboratory since the laboratories were conducted in teams of two students. To account for this, a web-based survey response was weighted as two responses. In some cases in which one of the two students also responded individually, the web-based survey was weighted as one response. Observations and interviews were conducted with four teams of students at the time they were using CyberLab. Three teams were observed while they carried out the laboratory experiment and one team was observed during the initial phase of the remote laboratory up to the Pre-experiment test.

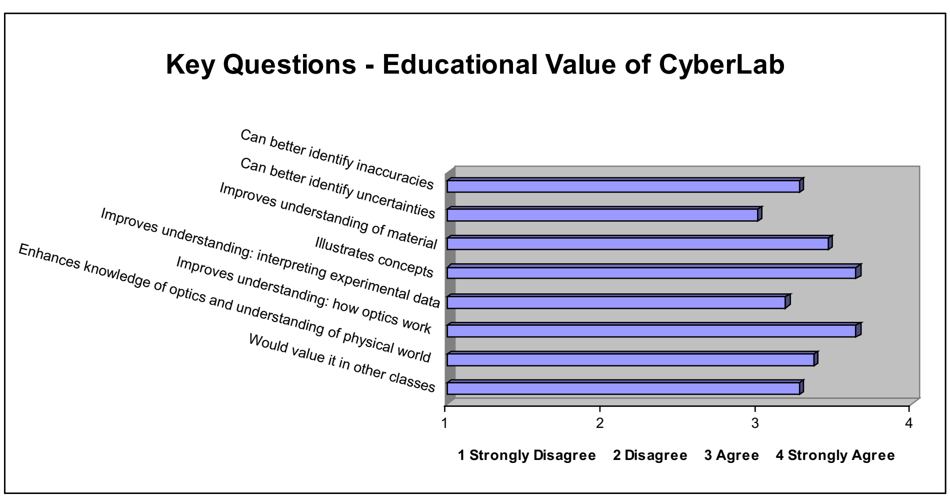

Figure 5. Survey results indicating the educational value of CyberLab

The anonymously collected data concerning the first pilot program reveal positive reactions of the students to questions regarding the educational value of exposure to the physical reality provided by CyberLab, as shown in Figure 5. Students expressed that they increased their understanding of errors. Specifically, students reacted positively to the usage of the remote laboratory environment. Students agreed that the remote laboratory experiment helped to illustrate concepts learned in class. In addition, they felt that the remote laboratory was an effective tool for enhancing their knowledge of optics and their understanding of the course material and the physical world. They had an increased understanding of how optics work and how to interpret experimentally measured data as well as an improved ability to identify the inaccuracies and uncertainties between experimental and numerical data.

With the exception of server problems (which have been corrected since the study was conducted), students were satisfied with the user-interface and the ease of program navigation. They found the experimental data useful and educational, but students also expressed the desire for greater autonomy in the control and alignment of the experiment in order to bring the remote laboratory environment experience closer to a "hands-on" experiment (these capabilities have been added to later versions of CyberLab). Students emphasized that the strengths of the remote laboratory environment were the ease of operation, ease of access, efficiency and convenience. The Notebook proved to be an effective step-by-step mechanism to ensure that students followed laboratory procedures closely from reading the proper texts to taking a Pre-experiment test prior to beginning the actual laboratory experiment. One student referred to the remote laboratory environment as the best alternative to a “real hands-on” experiment.

Remote Laboratory extensions

The new paradigm of on-line laboratories presents several challenges to be overcome: scalability, course administration, data management, collaboration between students, and evaluation of educational merit. Scalability is a critical issue required to extend a web-based laboratory system to serve the demand for education. Such expansion requires a distributed data management system, scalable network infrastructure, resource administration, and a standard of organization for online-laboratory education. Development of such organization will be a substantial challenge in allowing a standard method of being able to extend laboratories to include a wide range of equipment and communication standards. In order to expand beyond a few students and experiments, a methodology of data collection, hierarchical organization, and integration with databases must be established, and applying that knowledge to enhance the learning process.

Once collection and management of student learning data has been established, understanding and enhancement of online-education can be improved by analysis of such data. This will allow the capability of understanding and quantifying student’s learning patterns, approach to problem solving, and common mistakes. Such data can then be used to improve the level of interaction with the user interface. Automated comments and suggestions could similarly be improved by understanding students’ learning patterns. Research can be conducted towards designing computer algorithms that assist in the development of a comprehensive understanding of how students approach laboratory problem solving.

In our opinion, in designing on-line laboratory systems, the educational goal must be the main priority. Although many labs can be designed that function correctly, without this priority they can lack educational value. When well-defined educational goals are determined, these can then be used as the philosophy for the lab’s design and the criteria in evaluating its educational merit. Effective and efficient on-line laboratory systems must be evaluated from multiple perspectives, not solely based on the viewpoint of system developers. This process involves experts from various fields such as: educational psychologists, language specialists, statistical analysts, communication test theory, social scientists, anthropologists, culture and learning specialists, and education specialists in achievement motivation. By quantitatively analyzing the performance of students, such an evaluation can be made and used to continuously improve the educational value of such laboratories.

The concept of web-based experiments have several important traits: live streaming data, remote control of a real lab, global access, flexible scheduling, and learning through collaboration. When such a lab is implemented with organization based on educational goals, a new standard can be established for the learning of lab skills. As resources and content can be easily varied, CyberLab offers the possibility of providing customized education, when and where students want it.

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