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The Internet Science Institute and the Incorporation of Laboratory Experience with Web-based Education

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Abstract

Rapid advances in Web technology have created an opportunity to involve students in the scientific method in an affordable and attractive manner. This project's focus is the incorporation of laboratory experience with Web-based educational modules. The materials are integrated into a Web site, http://isi.loyola.edu., the Internet Science Institute (ISI).

Educational materials developed on the pilot grant are summarized. The topic of the first module developed was pendulum motion. It has been discussed elsewhere.

To add lab experience to Web learning, the Interactive Web Board (IWB-1) was developed. The IWB-1 has data acquisition via the audio port of a standard PC, which allows the computer to monitor all activity performed on the board, thereby serving as an "instructor". The IWB is a breadboard that may be used to construct electronic circuits. It is also possible to use it as a general data collection device for science experiments.

An example of a new module for the ISI covers topics in robotics and control systems. The module utilizes the LEGO-Dacta® system and its focus is on the roles played by sensors, actuators, feedback, and software elements in the design of a robotic system.

The equivalent of the scientific method in applied math is the building and testing of math models. One application is in modeling the prices of investments; i.e. "Mathematical Finance". The first level of this applied math module develops the ideas behind pricing an option on a stock. The module incorporates HTML with Java applets to help with calculations.

Evaluating the efficacy of Web-based educational materials requires a multi-faceted evaluation scheme. The first tier evaluates how materials have been incorporated into the learning experience. The next tier evaluates usability in three ways: (a) Observers are given fixed-question data sheets. (b) Observers record more qualitative observations. (c) A survey is administered to the student users, which collects demographic information and opinions. In the final tier, students take pre-and post-tests to see if learning goals were achieved.

Materials from this project will be packaged so that they can be examined and downloaded from the project site, and also made available via CDROM.

I. Introduction

In 1998 NSF/DUE funded a "proof-of-concept" project for Loyola College to develop innovative materials for learning science by doing science – using Web-based techniques to make it attractive and affordable – including interfaces to physical experiments. The materials are integrated into a Web site http://isi.loyola.edu. -- the Internet Science Institute.

The overall purpose of this project is to improve learning of science by involving the students in all phases of the scientific method, including physical experimentation.

II. Background

The use of hypertext and multimedia in science education has grown rapidly in the 1990s. The emergence of the Web in mid 1990s has added new opportunities for using text, audio and video material in education[1]. A meta-study of hundreds of studies of computer-based learning in many fields at all levels (K-16) found that computer techniques can raise scores from 10 to 20 percentile points and reduce times to reach goals by 33 percent[2]. Researchers at RAND Corporation also make the case that the Web and information technologies will transform the processes of learning[3].

Most efforts are exploratory and rudimentary, tied to individual courses, and often developed by "early adopters," instructors with a personal interest in the Web, rather than through a systematic approach. Science educators are just beginning to cope with complexity of designing courses that incorporate the Web. Many efforts are devoted to putting course outlines online or uploading existing courseware. Because the use of the Web in instruction is still in its infancy, relatively few research results on its effectiveness for learning have been published, and one should not assume that techniques are better just because they are new.

To Internet enthusiasts, it seems obvious that Web-based learning can be better than earlier approaches. However, it must be done right to be effective. A few studies suggest little or no improvement in performance among students using computers over those without technology[4]. Teaching students using hypermedia technology has proven more difficult than some have anticipated[5]. A recent paper cautions that Web-based learning must be relevant to the student group if it is to be successfully incorporated into normal coursework[6].

The key is that designing educational material for Web-based learning requires the development of learning methodology suitable for this new medium. It is clear that careful experiments of usability and effectiveness are essential. While there are many Web-based learning projects underway, few have provided proper controlled measurements of their effectiveness, except for the common approach that students in class B liked the new techniques better than those in old class A.

Contemporary brain science, learning theory, and educational psychology confirm that students learn best by a variety of complex and interactive, biological and cultural modalities. Here, the potential of Web-based learning is especially significant. Consistent with the theories of Howard Gardner and the earlier work of Dunn and Dunn, networked computers can potentially provide many different learning situations: linguistic-verbal, mathematical, interpersonal, musical, spatial, naturalistic, philosophical, and kinesthetic, pertinent to different "intelligences" and "learning styles."

III. Summary of Results from Prior Work

A. Current Features of the Internet Science Institute Site

The 1998 NSF pilot grant for course and curriculum development (CCD) was awarded to permit experimentation with the Web as a medium for learning of science by doing science.

The pilot project was developed as a Web site to be accessed both locally (as an intranet) and as a Web site for broader use. The site contains locally produced materials and also courseware and other science teaching resources mined from the Web. The user interface is a "research institute" in cyberspace, the Internet Science Institute. ISI includes "wings of a building" for physics and computer science. For example, as in a physical building, the Physics Wing contains an information desk, classrooms with courseware, labs with virtual experiments, a departmental library, etc. Rooms contain multimedia materials that can be examined by a Web browser.

While the ISI structure described above provides a framework for Web-based education in general, the main theme here is learning science by doing science. It is relatively easy to provide hand-on experience with most phases of the scientific method: construction of hypotheses, background research, simulations, communications of results, etc. The real challenge is extending the student's lab experience to the physical world. The intent is to use fully use the resources of the Web and standard PC, plus inexpensive auxiliary materials, to complete the learning experience. To illustrate this novel concept, two specific experimental modules developed on the pilot grant will be summarized.

B. A Multilevel Classical Experiment

The topic of the first module is the motion of the pendulum, and the structure that we used guides students through three levels of experience. The first is a "hands-on" lab that uses readily available materials. For example, students are guided by the courseware to conduct experiments of the effect of the pendulum mass and length on its period. A second, more "refined," lab experience then layers on more detail to the phenomena under discussion, and focuses on data acquisition, test and measurement issues. This level guides the student to use commonly available Microsoft Office 97 applications to analyze and report the experimental results. The third level of the module is based on mathematical models and simulations (Java applets) and conceptually focuses on the most sophisticated aspects of the phenomena or their broader application.

This module has already undergone extensive usability analysis in several engineering and non-science classes. The results are described in a paper submitted to the 1999 Frontiers in Education conference, sponsored by the IEEE and ASEE, held in November 1999 [7]. In addition to the obvious analysis of student lab notebooks and survey instruments, social science students were used as observers as others experimented, to capture detailed information on the fits and starts of progress through the modules.

C. The Interactive Web Board

Physics education research in the past decade has demonstrated that the learning of physics is greatly enhanced by "hands-on" activities [8]. Two of the most successful innovations in physics teaching have been laboratory-based [9,10], foregoing the traditional lecture completely to allow students time to construct their understanding of the material as active participants. A major difficulty with all lab approaches, however, is the cost of the courses in personnel and equipment. The use of computer simulations in place of physical apparatus has been suggested as one means of reducing costs. Lillian McDermott, however, urges caution, "Even a highly interactive computer program provides no guarantee that students will be engaged at a sufficiently deep level for significant concept development to occur". [11] Pricilla Laws, suggests similarly that even the best of simulations students will often enter "video game mode" where they blindly manipulate the program parameters [12] with no real learning occurring.

Properly used though, computer simulations can be an important component of physics instruction, because much of physics deals with time-dependent phenomena that are ideal candidates for simulations and animations. The speed of desktop computers now permits useful, interactive simulations to be delivered over the Web. Many people have consequently begun to generate applets for physics education. Wolfgang Christian is developing scriptable applets, which he calls Physlets [13] that can be modified to suit individual instructors. The *Physics 2000 Project* [14] at the University of Colorado has developed a huge number of applets to accompany their on-line physics tutorials. These simulation applets have generated an enthusiastic response from physics teachers. A common complaint, however, is that the Web has not yet been able to provide genuine laboratory experience.

To add this lab experience to Web approaches, the first generation of the Interactive Web Board (IWB-1) was developed during the pilot ISI project. The IWB is a breadboard that may be used to construct and test electronic circuits of varying degrees of complexity with plug-in components, just as one would do with other familiar breadboards. The IWB-1, however, has the added functionality of direct data acquisition by a standard PC via its audio port, which allows the computer to monitor and display all activity performed on the board. The prototype consists of 24 pins and a collection of circuit elements (switches, light bulbs and batteries). The accompanying program is a Web-accessible Java applet that recognizes circuit elements on the

Board and generates an on-screen reproduction of the physical circuit as it is constructed. A paper on IWB-1was presented in March 1999 to the American Physical Society on IWB.

IV. Full Development Project

The full development of the ISI project is planned to proceed in a number of phases. Each is briefly described below.

A. The Interactive Web Board

Building on the IWB-1 prototype described above, the authors plan to construct a more advanced model (IWB-2) that will more closely resemble a standard electronics-training breadboard. A much larger array of circuit elements will be added to the system, including resistors, diodes, capacitors, inductors and several logic elements. Also included will be voltmeters and current meters whose output is displayed via the computer. Central to the system is an intelligent monitoring program that can guide the student in wiring and debugging a circuit. While much of this program will be a generic circuit-parsing system, other components will be specific to the circuit being built and the context (i.e. elementary education students, or graduate students). To ensure flexibility, a meta-language will be developed (within the Java applet format) to allow relatively easy generation of the program for each new circuit.

The experiments that will be done on the IWB are the experiments that are currently done in many classrooms and labs [15,16,17]. The computer interface, however, allows the computer to play the role of the instructor who usually watches over the shoulders of students to point out flaws in their logic. Since the Web Board and circuit elements should cost less than $20 to produce, it will be possible for students to buy the kit, plug it into their home computer, go to the website describing the various projects, and experiment with them. The website will contain introductory material as well as links to advanced material on circuits and applications to encourage the student to go beyond the particular experiment.

Since the IWB is a data acquisition device, it is also possible to use it as a data collection device for science experiments. Various transducers can be added as circuit elements, so the board can be used to record light intensity, positional information, pH, etc. Since the board can recognize objects that are plugged into it, it can also be used as an interactive lab bench that "understands" the physical set-up of the experiment and so can guide the investigator through the experiment. A chemistry module might be constructed, for example, which would guide students through genuine, analytical chemistry experiments.

B. Robotics

A second example of a new module for the ISI would cover topics in robotics and control systems. The hands-on portion of the learning module would utilize the LEGO-Dacta® system, which includes sensors, building parts, software and communications to create open-ended autonomous robotic systems. It has already been shown that robotics is an excellent subject for motivating students. It sparks the imagination of most children and adults, being a staple of science fiction stories. The LEGO® company itself has spun off a separate LEGO® Mindstorms retail division for just such robotics educational systems. The phrase "mindstorms" comes from an early proponent of innovative education for children, Seymour Papert. He and his colleagues originally developed the LOGO® robotics system to teach young children about programming and problem solving. Questions remain however about access to such educational materials, as the retail product is fairly expensive. In addition, such open-ended investigation without the guidance of any pedagogical structure can prove frustrating to children.

The key concepts that will be the focus of this learning module are the important roles played by sensors, actuators, feedback and software elements in the design of a robotic system. Although the proposed new module on robotics requires some fairly expensive equipment for the "hands-on" portion of the lab, we may eventually be able to implement the same lab fully over the Web. Such work has already been pioneered at a number of locations including some well-published examples in astronomy. The utility of such remote control over the Internet as a scientific advancement is unquestioned. Its feasiblity for science and engineering education has not been assessed, but it does capture some of the advantages inherent in a true "hands-on" learning experience.

C. Model Building in Applied Math

The equivalent of the scientific method in applied math is the building of math models and testing them against the real world. First one starts off with a simple model, tests the model against real data, and then increases the complexity of the model as necessary.

One application in which students can easily be motivated is in modeling the prices of investments; i.e. "Mathematical Finance." This field, which includes pricing of financial derivative securities, has very recently become a part of mainstream mathematics [18]. One example of such derivatives is a call option on a stock. This gives the holder the option to buy a stock for a fixed price in the future. Of course, the holder of the option will only exercise the option if it will result in a profit. The mathematical task is to find a “fair” price for the option. Validation of the model with the real world is done by comparing its results to those established by actual market trading in these options.

Researchers began working in this area at least twenty years ago [19], and gradually the material was introduced at the graduate level [20], often as part of a course in stochastic differential equations [21]. Recently, a number of graduate programs have sprung up, and several undergraduate texts have been published [22,23].

By working through a module, a student learns about a math topic using a Web browser and a computer algebra system such as Mathematica as a worksheet. For some modules, Java applets are included to heighten the interaction. The first level of this applied math module would develop the ideas behind pricing an option on a stock, starting with a one-step binomial tree. This is the simplest possible model for stock prices in which the stock prices can either move up to one possible price or down to another possible price. The one-step model would be fully developed in HTML with a Java applet to help with calculations.

At the second level, we introduce a more complex model, namely the multi-step binomial tree, to provide better estimates of option prices. Here we will use an Excel spreadsheet in conjunction with a Web browser so that a student can see all the nodes on the tree. This improved model should outperform the one-step model. The material up to this point should still be accessible to a freshman student. We will then discuss how, as one allows the number of time steps go to infinity, we get a continuous distribution for the stock price, namely the lognormal distribution. Here we will assume that a student has had a little probability theory. At this stage we will start to employ Mathematica, writing a couple of small "do loops" to price an option.

At the third level, in search of a more accurate model, we then introduce geometric Brownian motion. This is a continuous time and space model for a stock price. This material is at the advanced undergraduate level. Intuition for the model will be developed using Java applets. Again, current market data will be used by students to price options using this formula, with the assistance of Mathematica.

D. Project Evaluation Procedures

Evaluating the efficacy of Web-based educational materials requires a multi-faceted evaluation scheme. There must be a summative evaluation, that is, the effectiveness of the program must be measured against its stated aims. In addition, it must be evaluated for its usability. Computer-based educational experiences must be evaluated along three vectors--context, interaction and outcome. By context, they mean the rationale for using the material and the way the material is incorporated into the overall learning environment. Interaction looks at the way students use the materials. Outcomes refer to the achievement of specific learning objects. Based on these ideas, a four-tier evaluation strategy for the ISI is used:

(1) The first tier will be to evaluate how materials have been incorporated into the learning experiences. After the semester, the faculty will be asked to submit their syllabi, indicating the role the ISI material played in course. Pre-course and post-course interviews will capture the expectations and experiences of the involved faculty of how the material fits into their course.
(2) The next tier evaluates usability in three ways: (a) Observers will be given fixed-question data sheets to assess whether students were able to work through the modules properly in a reasonable time. (b) Observers will also record qualitative data based on their observations, i.e. reasons for delays or other problems. (c) A survey will also be administered to the student

users, which will collect demographic data (age, gender, computer experience, major, etc.) and their opinions on the usability of the modules. Moreover, every module will have specific files that must be generated to complete the educational experience. Those files will be forwarded to the module faculty and ISI evaluators for review.

(3) The next tier will focus on learning outcomes. Faculty will develop specific learning objectives, which the ISI material is expected to achieve. The learning objectives will include specific fact-based information that is intended to be assimilated through the use of ISI material as well as broader conceptual learning. Students will take a pre-test and a post-test to see if those learning goals were achieved.

(4) The final step in the evaluation process will be to correlate the data gathered from the tiers described above. In this way, the relationships among the context in the use of the material, the usability of the modules, and the educational outcomes can be better understood and applied to ongoing development of materials.

The evaluation methodology described above will provide a steady feedback loop for ongoing development of materials.

Another paradigm for measurement of learning effectiveness is to apply the techniques of ergonomics and human-computer interactions (HCI) to testing the usability of Web-based learning techniques. Actually, what is required is the logical extension of HCI to human-network interactions (HNI), a term that was apparently coined by one of the authors in a paper posted on the Web in 1998 at http://justice.loyola.edu/~rds/. The HNI viewpoint takes explicit account of the special aspects of Internet based platforms versus standalone computer platforms. For example file download delay is the central issue of Web-based learning. Survey results show that users find it to be by far the most serious problem: users give up after a certain delay that varies with the individual.

A cornerstone of HCI development is the inclusion of usability labs to test the effectiveness of different designs. To support the HNI paradigm, one of the rooms in the ISI will be a usability lab. Students of HNI would be able to develop usability tests on interface design characteristics, make those tests available to the network, then collect, analyze, and report the findings of the testing.

Information products of the study will be packaged so that they can be examined and downloaded from the project site http://isi.loyola.edu, and via a CDROM available for the marginal cost of its production. This medium would permit other sites to use individual modules locally without incurring long file delays.

V. Conclusion

This project seeks to improve teaching in science courses by learning of the methods of scientific inquiry by direct involvement. The recent report, "Shaping the Future," [24] of the advisory committee for NSF's education activities (EHR) has many findings, but its central recommendation

is, "the goal--indeed the imperative--deriving from our review [is that]:
All students have access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology, and all students learn these subjects by direct experience with the methods and processes of inquiry".

While educationally sound, meeting this goal of learning-by-doing science for all students presents a serious challenge; few universities can provide so many laboratories. Without experimentation, some courses might remain surveys of the terminology, history, and biography of science without providing direct experience of what constitutes scientific truth.

The idea of all students learning science by doing science is not new; laboratory science was a common requirement for all students until labs fell out of favor in the 1980s, probably because of their expense and unpopularity with students--and with professors who had to find time to publish research work, or else. What is needed is really a renaissance of proven methods, but one that exploits modern technology to make experience with the scientific method affordable and attractive to students and professors.

What is new in the late 1990s is that rapid development of the Web has created an opportunity to provide all students with involvement in the full range of pure and applied science methods in an affordable and attractive manner. This project provides a focus on completing the full range of learning of scientific methods by incorporation of real laboratory experience with the information delivered over the Web.

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Suzanne Keilson is Assistant Professor of Electrical Engineering and Engineering Science at Loyola College. She is a researcher in biomedical engineering and signal processing, specializing in the auditory system, including brain and neural issues. She developed the classical mechanics module and is currently developing the ISI module on robotics and control theory.

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