

ON LINE EXPERIMENTS - THE RESULTS OF THE ONLINE WIDENER LABORATORIES

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Abstract $\frac{3}{4}$ The Online Widener Laboratories (OWL) provide an interactive online experience that is used in several web-enhanced courses. The extensive use of JAVA applets for complex simulations allows for 24/7 availability and multiple simultaneous users using a moderately sized server. This system has been used to supplement both laboratory courses and conventional lecture based courses. In the laboratory courses, the online system provides an interactive experience to help students organize data and plan their experiments and analytical approach. In lecture courses, this system allows for interactive homework assignments that simulate real world problems. Students' responses have been generally positive. Measurements of the systems effectiveness include time-savings in the actual laboratory and student evaluations and measures of time spent working modules. Also, evidence suggests that students use the web-site on their own to study topics not required for their particular course.

Index Terms $\frac{3}{4}$ Internet, Process Control, Virtual Laboratories, Web-Enhanced Education

INTRODUCTION

The Online Widener Laboratories (OWL) are the result of an extended effort to incorporate interactive web-based instructional modules in a variety of courses. The goal of OWL is to provide an interesting and realistic interactive experience that simulates important engineering concepts and supplements other instruction. OWL consists of two laboratories that have similar organization and software architecture but different goals and uses. The first online laboratory, the Virtual Chemical Engineering Laboratory is designed to prepare students to perform actual experiments in a Chemical Engineering Laboratory. The Virtual Process Control Laboratory is designed to provide a realistic experience in a conventional lecture based course. Both laboratories consist of a series of highly interactive instructional modules designed around a particular concept or experiment. The Virtual Chemical Engineering Laboratory is used as a supplement in Chemical Engineering Laboratories that are taken by students in that course only. The Process Control Laboratory is used in courses taken by Mechanical and Chemical Engineering students.

The heart of each instructional module is an interactive simulation that recreates a process or experiment. The interactive simulations are contained in JAVA™ applets

delivered by the web server to the client (user's) computer. Applets run on the user's computer in the browser window. This architecture reduces the server's workload by shifting computational load from the server to the client and eliminates delays to the users' responses caused by transmission delays between the client and the web server. Therefore the user sees a fast response and the server is able to accommodate more simultaneous users than would be possible if it performed the simulations itself. Using this approach, OWL has successfully accommodated 21 simultaneous users in a class room setting.

A disadvantage of this method of delivery is that the applet must be transmitted to the user who may be connected to the Internet through a modem. Therefore, the size of the applet must be kept small. Otherwise, users might object to long delays when the applet is transmitted. A size of 60k was specified as a target for the size of the applet. This size typically requires between 10 and 40 seconds for a page containing the applet to load when connected to the site using a typical Internet Service Provider, such as AOL, over a 58.8 modem.

THE VIRTUAL CHEMICAL ENGINEERING LABORATORY

Goals and Description

The Virtual Chemical Engineering Laboratory (VCEL) was developed to supplement the existing Chemical Engineering Laboratories. One of the major purposes of VCEL was to familiarize students with the data analysis techniques for an experiment prior to their entering the lab so that they would use lab period time more efficiently. The modules in this laboratory are designed for use in Widener's Chemical Engineering Laboratory courses (Ch.E. 327 and Ch.E. 427) but some modules can be used in other courses ranging from introductory fluid mechanics (the Viscosity experiment and venturi calibration) to mass transfer (the McCabe Thiele calculation modules).

A typical module consists of a brief introductory screen, designed to introduce the experiment and the equipment used. The student then proceeds to the interactive module. A typical module is shown in figure 1. With the exception of the distillation simulation, the interactive modules have active instructions on the right to make their use intuitive and simple. The current step is highlighted so that the user knows how far along he or she is in the module. For many

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of the modules, data analysis is performed online using the “Virtual Lab Databook”[1] which allows students a variety of methods for plotting and analyzing data. An online “pocket calculator” is available for simple calculations. Online help is provided using the buttons at the top of the screen.

For most students, the modules’ help and the on line instructions are sufficient to learn the concepts and successfully master the module. Students have been able to use the modules from the online help. If the student does encounter difficulties, the student can email the class instructor who can provide additional guidance and help. When the student completes a module, the student has had the experience of actually using engineering concepts and skills in a realistic and interactive manner.

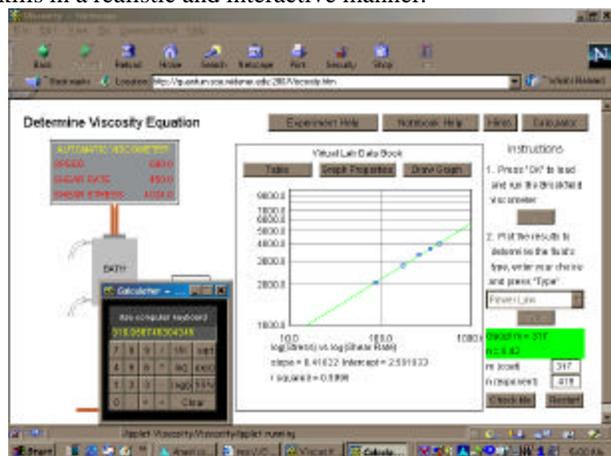


FIGURE 1
TYPICAL EXPERIMENT FROM THE ONLINE VIRTUAL LABORATORIES
(THE ONLINE POCKET CALCULATOR IS IN THE LOWER LEFT)

Operation of the Data Book

The Virtual Lab Data Book has two means of displaying data: a tabular display similar in appearance to a spreadsheet. Students may scroll through the table using buttons in the corners of the table. A graphical display that also automatically fits the data to a straight line is also available. The graphical view is controlled by an interface that uses standard drop down boxes to be intuitive to use. Students use ordinary buttons arranged across the top of the data book to switch between the three views. The data book automatically records data. The student must determine the appropriate method of analysis to obtain a solution.

The use of the “Virtual Data Book” to analyze data generated by a module is straightforward. After students complete collecting data, they select the columns to plot and the transforms from the control view and click on the “Draw Graph” button to generate the plot. The least squares fit is drawn and its values are automatically displayed on the graph display.

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Distillation Simulation

The distillation simulation was significantly different than the other modules in this portion of OWL. It was designed to provide students an opportunity to become familiar with the operation of our Technovate batch distillation column prior to actually performing experiments on it. For many students, the distillation column is the largest and most intimidating piece of equipment they have encountered. The prototype has automatic control and requires considerable skill to operate. Prior to the creation of the Virtual Chemical Engineering Laboratory, students spent considerable laboratory time learning to operate the unit.

The distillation simulation was designed to function much as training simulators used in industry. A detailed computer simulation of the prototype had to be developed to serve as the engine for the simulation [2].

Following the example of industrial simulations, a goal of this module was to preserve, as much as possible, the “look and feel” of the operation of the prototype in a JAVA™ applet. Figure 3 shows a screen shot of the simulation. The image on the left represents the actual column with manual controls and flowmeters. The student can toggle the display on the right of the screen to show either the rear of the column (where some valves are located) or a graphic representing the computer monitor as it appears when running the Factory Floor™ software used to control the column (shown in the figure).

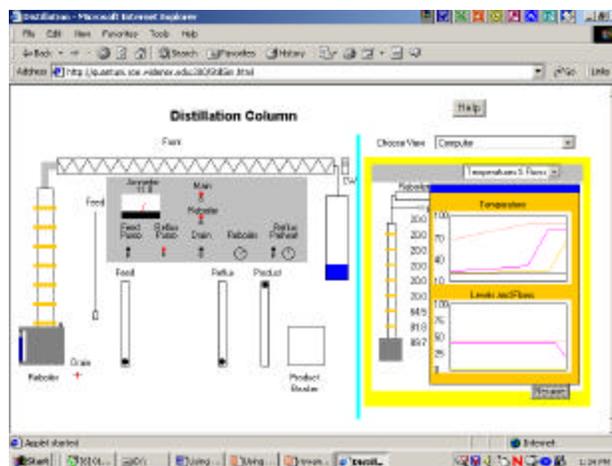


FIGURE 2
SCREENSHOT OF DISTILLATION SIMULATION

Unlike the other modules in the OWL site, this module is not intended to be intuitive to use. Operating instructions for this module are the same as for the prototype column and are included on the site as a *.pdf file. Additionally, a demonstration module allows users to practice opening valves, throwing switches and performing the other activities required to run the simulator. Students have not experienced any difficulty running the simulator and performance on the prototype has dramatically improved (see “Conclusions”).

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THE VIRTUAL PROCESS CONTROL LABORATORY

Goals and Description

At Widener University, Process Control is taught in a standard three-credit course taken by both Mechanical and Chemical engineering students. This course does not have a regularly scheduled laboratory component. The Virtual Process Control Laboratory was constructed to allow students to have experiences tuning controllers and observing various control schemes in simulations that behave in manners similar to real examples. It is designed to supplement the lecture component by allowing interactive homework, in class demonstrations and a means of testing student performance.

Because the course is taken by both Mechanical and Chemical Engineering students, the modules use processes such as heaters and mixers that cut across disciplines, so that the site can be used by a wide variety of engineering students. The Virtual Laboratory has the advantage that the simulations use an accelerated time scale (1 second of real time ~ 4 seconds of simulated time) so that students may complete assignments more quickly than in a conventional laboratory. Additionally, the simulations all have a “Pause” button that allows users to temporarily halt the simulation to examine the simulations’ responses or calculate the controller settings.

Again, the user interface is patterned after those generated with Factory Floor™ software a commercial software product developed for use with OPTO 22™ programmable logic controllers and used in the Chemical Engineering Laboratory. A sample screen is shown in Figure 3.

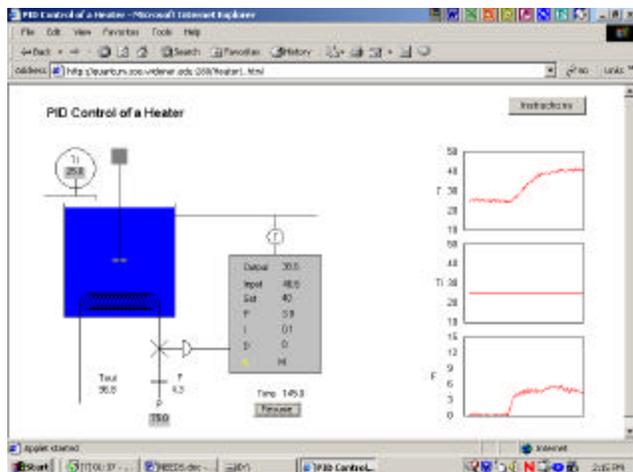


FIGURE 3

A SIMULATION OF A WATER HEATER CONTROLLED BY A PID CONTROLLER

Instructions, along with descriptions of various tuning schemes, are provided in the “Instructions” section of the

web site. Data entry is patterned after Factory Floor’s™ data entry method. To change a numerical value, such as a set point, the user merely moves the mouse cursor over the value. A box appears around the value. The user then clicks the left mouse button to open a popup window. Next, the user enters the new value in the box and clicks the “OK” button in the popup window. The window closes and the new value is entered.

The plots on the right scroll automatically when module is running, simulating the plotting functions available on commercial process control software. All the modules have the capability of adding random noise to simulate a noisy signal. In a few of the modules, the user can control the amount of noise so users can explore the significance of signal noise in control.

Early in the development of this laboratory, a need for graphical analysis of the plots was observed. This need was filled by allowing users to click on any of the dynamic plots with the mouse. This action causes the simulation to pause and a large plot appears as shown in Figure 4. As described in the online instructions, students can then draw lines, measure values and determine properties necessary to tune the controllers or measure results.

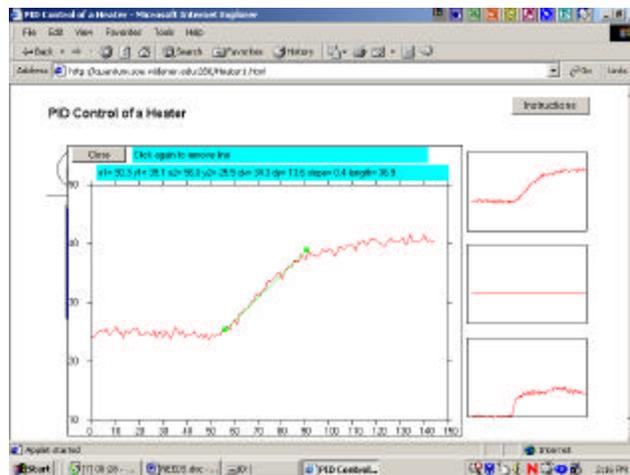


FIGURE 4

SCREENSHOT SHOWING THE LARGE PLOT FOR GRAPHICAL ANALYSIS

The lines students draw are persistent objects, so that a student can draw a line on one graph to mark an event, then switch to another plot. When the student clicks on another graph, the lines he or she has drawn reappear. In this way students may easily measure such items as dead time.

Uses of the Virtual Process Control Laboratory

Since each simulation can be used for a variety of purposes, detailed instructions and goals were not included in these modules. Furthermore, because there are a variety of experiments performed using the same module, the monitoring software was designed to function as a history of

students' actions. The instructor distributes experiments in class for the students to perform, either as homework or an in-class assignment. Students turn in their results which are graded manually much like regular assignments. Because the site is available on a 24/7 basis the modules may be used as in-class demonstrations, homework assignments or for questions in tests. Students or faculty do not have to reserve time on the site, another advantage of the architecture of the OWL system.

Tuning Controllers

The most obvious use of the Process Control Laboratory is in teaching controller tuning and measuring performance. This is a skill that is frequently difficult to present in a real world format unless some interactive methodology is used. Several of the modules in the Process Control Laboratory generate random numbers for process variables, ensuring that all users get unique values (and hence, unique controller settings). The fact that the site can be used when giving tests in a computer laboratory also emphasizes the importance of the topic.

Illustrating a Control Design

An advantage of the OWL Virtual Lab is that it is easy to simulate the control of identical processes using different control schemes, something that would be both difficult and expensive with actual processes. Furthermore, different users can run different control schemes for the same process simultaneously which would be impossible if actual processes were controlled online. Thus, several control schemes are used on the same simulated process to illustrate significant features of the design of control system. As an example of how this feature is used, the simulated water heater shown in figure 3 is used again to illustrate cascade control to accommodate changes in heating oil pressure and finally, feed forward compensation is added in another module to handle changes in feedwater temperature. At the completion of these modules, students will have gained both experience in practical controller tuning and insights into how each enhancement improves response to upsets.

A few of the other experiments for this Virtual Laboratory are described below.

Experimentally Measuring Bode Plots

A simulation of level control of interacting tanks has a user selectable sine wave input to the process. This module is used to have students experimentally determine a Bode plot over reasonable frequencies for the process. The experiment serves to provide a practical introduction to the topic of frequency response, which often is perceived as a difficult and highly theoretical portion of an introductory course in process control.

Multiple Input-Multiple Output Processes

The control of multiple input-multiple output (MIMO) processes is a significant topic in Process Control. This

topic is addressed using a model of a simple mixer in which two streams with different concentrations of a solute are mixed in a perfectly agitated tank. The purpose of the control scheme is to regulate both the overflow rate from the mixing tank and the concentration of solute in it. The first control scheme uses one controller regulates the flow of one input stream to maintain a set overflow rate, while a second controller regulates the flow of the second stream to maintain a set concentration. This module graphically demonstrates the importance of interaction in MIMO processes.

A second control scheme modifies the first by adding feed forward control to decouple the two controllers. An added feature of this model is that it exhibits nonlinear characteristics, so that tuning settings at a given operating point may not be optimal at a significantly different one.

Dynamic Matrix Control (DMC) and Internal Model Control (IMC)

In addition to conventional PID controllers, the Process Control Laboratory contains several models that illustrate other methods of control. Both DMC and IMC control [3] are used to control the same process model as conventional PID control schemes. Thereby allowing detailed comparisons of model predictive control to more traditional PID control schemes.

MONITORING SOFTWARE

A significant advantage of interactive web based instruction over other means of delivery is the ability to use the server to record and assess student performance. Beginning with the Fall 2001 semester, students using OWL were issued identification codes and passwords so that the instructor could monitor individual performance.

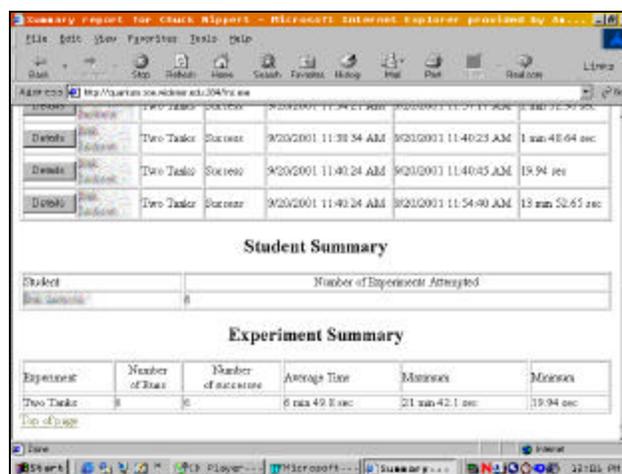


FIGURE 5
INSTRUCTOR'S SUMMARY

The instructor had password access to both class summaries. Figure 5 show a sample of the tables summarizing the performance of each student, and the class

performance on each module. The summary page also has a table summarizing each report from the modules. The instructor can examine a detailed report of any run by clicking on the "Details" button for that run.

The courseware can keep the instructor informed of problem areas as they occur. In the Virtual Chemical Engineering Laboratory, the software summarizes the students' actions and can determine if the student successfully completed a module. Each module in the Process Control Laboratory can be used for a variety of experiments. Therefore the software maintains a history file, similar to those maintained by industrial programmable logic controllers (PLC's) that the instructor can inspect to locate problems.

RESULTS (IT WAS FUN!)

A primary goal of the Virtual Chemical Engineering Laboratory component of OWL was to improve students' performance in the actual laboratory. Table 1 shows a comparison of Fall 1999 (before OWL was implemented) with Fall 2000 (the first semester of use). With the exception of minor maintenance changes, all experiments for both the junior and senior year were substantially the same in both 1999 and 2000. Data for 2001 is not shown because new experiments were added as a result of the time savings. It should be noted that the success rate for the experiments continued at the same level as in 2000.

TABLE 1
COMPARISON OF LABORATORY CLASSES BEFORE AND AFTER
OWL'S IMPLEMENTATION

| | Fall 1999 (Control) | Fall 2000 (using VCEL) |
|---|------------------------|---------------------------|
| Overall periods saved performing experiments (weeks) | | 2-3 |
| Average time to complete an experiment on the distillation column (weeks) | 1.6 | 1.0 |
| Equipment failures from student errors | 2 | 0 |
| Tray efficiency calculation correct on first report | 1/3 | 3/3 |
| Heat transfer calculation correct on first report | 1/3 | 3/4 |

Response to the Virtual Lab was positive. A recent graduate who saw the site commented that he wished Widener had the Virtual Laboratory when he was a student. All students were able to learn to use the data book from a short help screen provided in the Virtual Lab and accessible from the module. This was a concern when the site was first created. An improvement was noted in calculations in the senior year course for heat transfer experiment and batch distillation. These were the only two experiments for which

we had data regarding students' calculations for 1999. There was a savings of 2-3 weeks time in the laboratory over both courses.

These dramatic time savings required only a small amount of time on the students' part, as shown in Table 2. Usage summaries from the monitoring software reveal several interesting trends about student usage. The first is that the average time to perform any experiment is relatively short. The number of trials before success is higher for Chemical Engineering 1 than for Chemical Engineering 2, also, the average time to complete a module in the second course is lower than for the first. Perhaps this observation reflects the fact that the students in the second course are more familiar with the software. Detailed breakdowns of the success rate for each experiment indicate that the average time to complete a module varies greatly. This data can help pinpoint problem areas in OWL. These data are being used to modify and improve the design and ease of use of the modules.

TABLE 2
STUDENT PERFORMANCE IN ASSIGNED MODULES

| Course | Major | Average attempts before success | Average time to complete |
|----------------------------|-------------------|---------------------------------|--------------------------|
| Chemical Engineering Lab 1 | ChE | 2.7 | 8 min. 6 sec: |
| Chemical Engineering Lab 2 | ChE | 2.2 | 6 min 46 sec |
| Process Control | 48% ChE 52% ME | N/A | 11 min 43 sec |

Similar success was noted with the Process Control Laboratory. On average, ninety percent of the students during that period were successfully able to tune controllers (i.e. achieve approximately the same tuning settings as those obtained by the instructor using the same tuning method). Additionally, student response was positive as summarized in Table 3.

TABLE 3
SUMMARY OF STUDENT ATTITUDES

| Statement | % Agree or Strongly Agree |
|---|---------------------------|
| The Virtual Laboratory helped me learn to do Process Modeling | 77% |
| The Virtual Lab helped me understand process control. | 77% |
| The in class demonstrations help me understand process control issues | 70% |
| The simulations in the Virtual Lab seemed realistic | 60% |

The open structure of the OWL site also turns out to be an advantage. OWL contains over 20 modules distributed between the two laboratories. No course uses all modules. The usage data also indicates that approximately 10% of students who have passwords perform modules that are not required for their specific course while logged on. Although

this number is small, it must be taken as a minimum of the number of students who visit the site when not required. Students also have the opportunity of entering as a guest. They can simply click a "guest" button, which bypasses the normal login procedure. Such visits are not monitored. Therefore, it is reasonable to conclude that the modules are encouraging students to explore on their own.

Finally, anecdotal evidence also indicates the success of the OWL site in providing interesting experiences. A team of students was assigned a problem in the chemical engineering laboratory that required the students to run a module. The instructor software indicated that they had run the experiment successfully a total of 17 times, when asked why they had run the module so often, the students replied, "It was fun". Ordinary monitoring software included in most servers would only report the number of hits and not who had run the modules or whether they completed the module correctly, thereby giving the instructor a much different picture than OWL software reported.

CONCLUSIONS AND FUTURE WORK

The OWL site has been an ongoing project. Students have readily accepted OWL as part of their regular course work. To date, it has demonstrated that web-enhanced instruction can be successfully incorporated into both conventional lecture courses and conventional laboratory courses and provides enhanced opportunities for learning. The use of JAVA applets greatly expands the capacity of the server by shifting much of the work to the client. The site has accommodated 20 simultaneous users, something that would be impossible with the current hardware.

During its first year of operation it was noted that the text display of the history file for the history file from the process control modules was difficult for the instructor to use. Text display of the results from the chemical engineering laboratory modules was adequate. A graphical interface is being designed to allow the instructor to more easily monitor student performance in the process control laboratory.

The process control site allows us to include important topics such as tuning controllers that are difficult, if not impossible to cover in a conventional lecture course. For these topics, OWL provides the basis for in class demonstrations, in class assignments, homework assignments and testing. The degree of improvement in student knowledge in these topics is difficult to assess because, prior to the creation of OWL, there was an absence of means of measuring student performance, especially speed to perform a task, such as tuning a controller. The monitoring software provides a means to establish such reasonable metrics for important topics in control that were previously difficult to teach and almost impossible to measure.

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