Using Web Based Supplemental Instruction for Chemical Engineering Laboratories

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Abstract

The Virtual Chemical Engineering Laboratory (VCEL) was implemented as a supplement to the regular lab course during the fall of the 2000/2001 academic year. Successful completion of the on line experiments was required before students could perform the actual experiments. Comparison with the previous year indicated that the online experiments increased the students' abilities to perform and complete the experiments with reduced assistance from the class instructor. A significant reduction in time for student teams to complete experiments has been noted. Also, we noted an improvement in the ability of the students to perform calculations correctly. This paper discusses methods of incorporating virtual experiments into existing laboratory settings and the results of our experiences.

Chemical Engineering Laboratories at Widener

The chemical engineering laboratory courses are two one credit courses typically taken in the junior and senior years. The laboratory courses are not associated with any particular lecture course, such as transport phenomena, but instead draw on the entire curricula for their experiments. This presents both opportunities and problems. The major opportunity is that lab experiments can draw on any aspect of the curricula: control, thermodynamics, heat transfer, etc. A major concern, however, is that laboratory experiments may occur up to one year after the associated lecture course. As a result students may require considerable review before performing for some experiments. During the junior year course, most experiments are structured, with a primary emphasis on analysis of experimental data. In the senior lab, students are expected to design the experiments themselves. Experimental design, which is a minor portion of the course, is more fully covered in Widener's Senior Engineering Projects, which are required year long projects, taken by students in all disciplines. A large laboratory manual is distributed to the students at the start of each semester. The manual, which is revised each semester, contains general descriptions of the experiments and references.

Students are organized into teams of two to five students. Each team is given two weeks to complete an experiment. One hour weekly meetings are held in addition to the three hour laboratory period. The first meeting is held prior to the start of the lab to discuss the upcoming experiment. The instructor evaluates the first week's results and makes suggestions at the second meeting. A written report from the team is required a week after completing the experiment. This report is returned to the students the next day and must be revised by the following week. The revision allows students to correct both technical errors and writing errors. Typically, each semester has 14 lab periods. In both the junior and senior year courses, the first week of the semester is used for orientation and organization and the last week is used for an oral presentation of the final experiment. Thus, teams in both courses perform 6 experiments over the course of a semester. All the students in a course are scheduled to perform the same series of experiments, although occasionally the scheduled experiments may be replaced as a result of equipment malfunctions. A student will experience a total of 12 different experiments.

As an incentive, students are told that if they complete an experiment to the instructor's satisfaction in the first week, they do not have to attend the second week's laboratory period. This policy was implemented in the fall of 1999, when the author began teaching the course, so that the appropriate number of laboratory periods for each experiment could be determined.

Starting in the fall of 2000, students were required to complete the appropriate module in the Virtual Chemical Engineering Laboratory (VCEL) before starting an experiment. VCEL was placed on the author's web site and is available to anyone who has access to the world-wide-web (www2.widener.edu/~crn0001). Students who did not submit a printout of the completed experiment were required to perform the experiment in class before they could begin the experiment. This approach was used in both the junior and senior year courses.

Development of VCEL

VCEL was developed as a series of instructional modules associated with particular aspects of a laboratory experiment. Each module consists of a brief on line description, followed by an interactive module that simulates either the entire experiment or a portion of the experiment. The purposes of the VCEL are:

1. To provide practice in data analysis prior to real laboratory.
2. To supplement the existing laboratory manual.
3. To provide training and preparation so that laboratory time can be used more effectively.
4. To provide an opportunity to instill importance of planning and preparation before starting an engineering project.

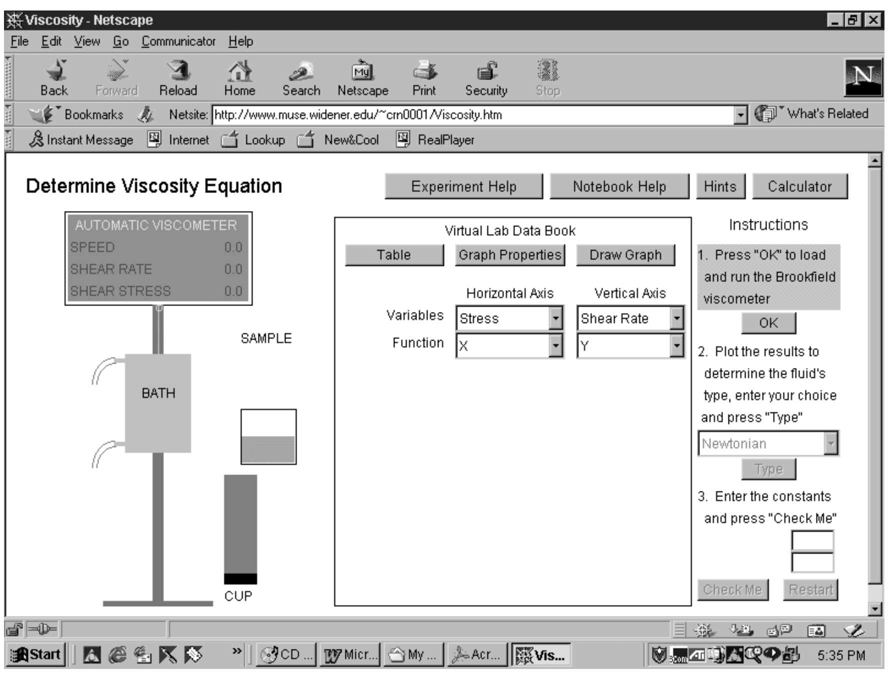
Web-based media was chosen for selected because:

1. The web based virtual lab provides around the clock availability.
2. Students are receptive to learning in this environment.
3. The virtual lab provides an interactive experience that can be made more open-ended.
4. The web site can be easily updated as additional experiments are added and existing ones are debugged.
5. The virtual laboratory has the potential of providing simulations of experiments that cannot be conducted in an actual physical laboratory because of limitations of time, safety or cost.

The amount of review required for seniors to operate the distillation column and perform the associated data analysis was a concern. As a result three of the ten modules dealt with distillation. One is a complete simulation of the operation of the distillation column and two dealt with methods of calculations (Murhpree tray efficiency, and McCabe-Thiele batch distillation). The remaining seven modules dealt with other experiments in both courses. In all, modules were prepared for seven of the twelve laboratory experiments scheduled for both courses.

As presented earlier[1], the on-line modules can be divided into two classes: 1. Those that provide simulated data for analysis to follow a programmed approach, 2. Those that teach laboratory techniques are more open ended. Modules in the first class are primarily used in the junior course, while the second type of module are only used in the senior course. In the data analysis modules, process models provide simulated data for analysis and the module automatically performs data collection. A "Virtual Lab Notebook" automatically records data and provides capability to plot data in a variety of formats. Active instructions and input are located on the right. This layout is patterned after the way a right handed student would set up a workspace on a lab bench, putting his/her notebook to the right of the equipment, so that they could record observations without hitting the equipment. Buttons across the top of the screen access additional instructions and, when needed, a "Pocket Calculator" for performing simple transformations, such as square root and transcendental functions. A sample screen is shown below in Figure 1.

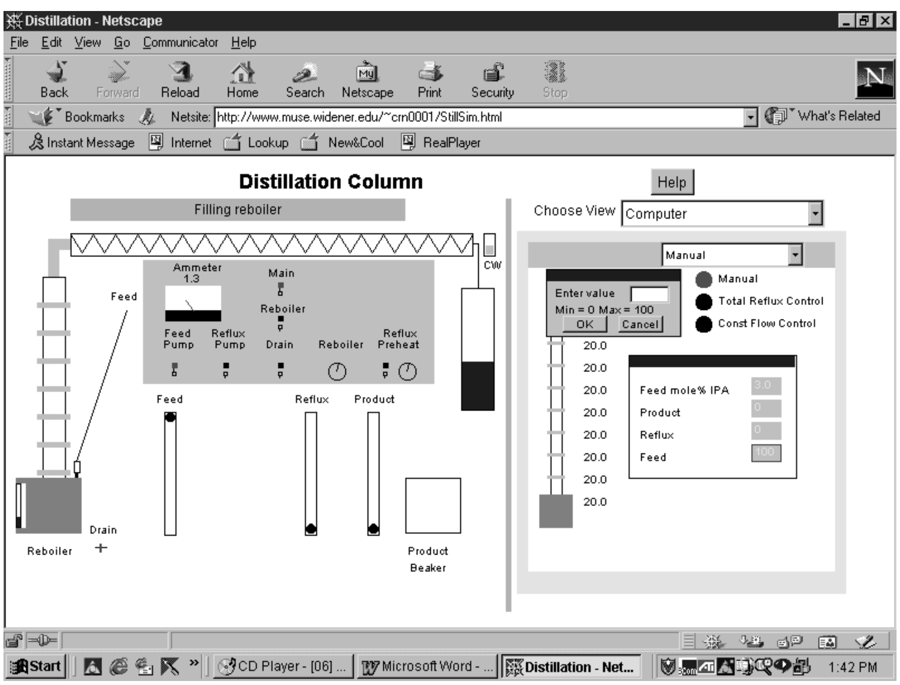
Figure 1
Screen of Start of Viscometer experiment as viewed with Netscape



The instructions on the right are active, with the current step highlighted in color and the necessary controls beneath the step. After the simulated data is taken, the student uses the graphing option to plot data and perform curve fitting. This configuration simplifies the use of the module.

The distillation simulation, on the other hand, is designed to familiarize the student with the operation of the laboratory distillation column. The prototype apparatus is a Technovate still operated in batch mode, distilling isoproanol and water. An OPTO LCSX programmable logic controller (PLC) provides automatic control and monitoring of key process variables. The PLC is interfaced to a computer running Factory Floor™ software on Windows 95. Although most temperatures and controls are monitored and regulated through the PLC, several controls, specifically the power supply, reboiler drain and feed, must be operated manually. Therefore, the start up and operation of the unit is significantly more complicated than the other experiments. A detailed operating procedure of this apparatus is included in the laboratory manual. The most complex module in VCEL is designed to provide students with a simulator on which they may practice operating the still prior to its operation. Therefore, this module provides, as much as possible, the "look and feel" of the prototype (Fig. 2). It also allows for controller tuning and limited simulation of other operating modes. For this experiment, the screen has two sections. The left side shows a graphic representing the still. On the right side, the user can display either the rear of the still (where various valves are located) or a representation of the computer monitor running Factory Floor software (shown in the figure).

Fig.2 Distillation Column experiment as viewed with Netscape
(the right side represents the computer monitor running Factory Floor software)



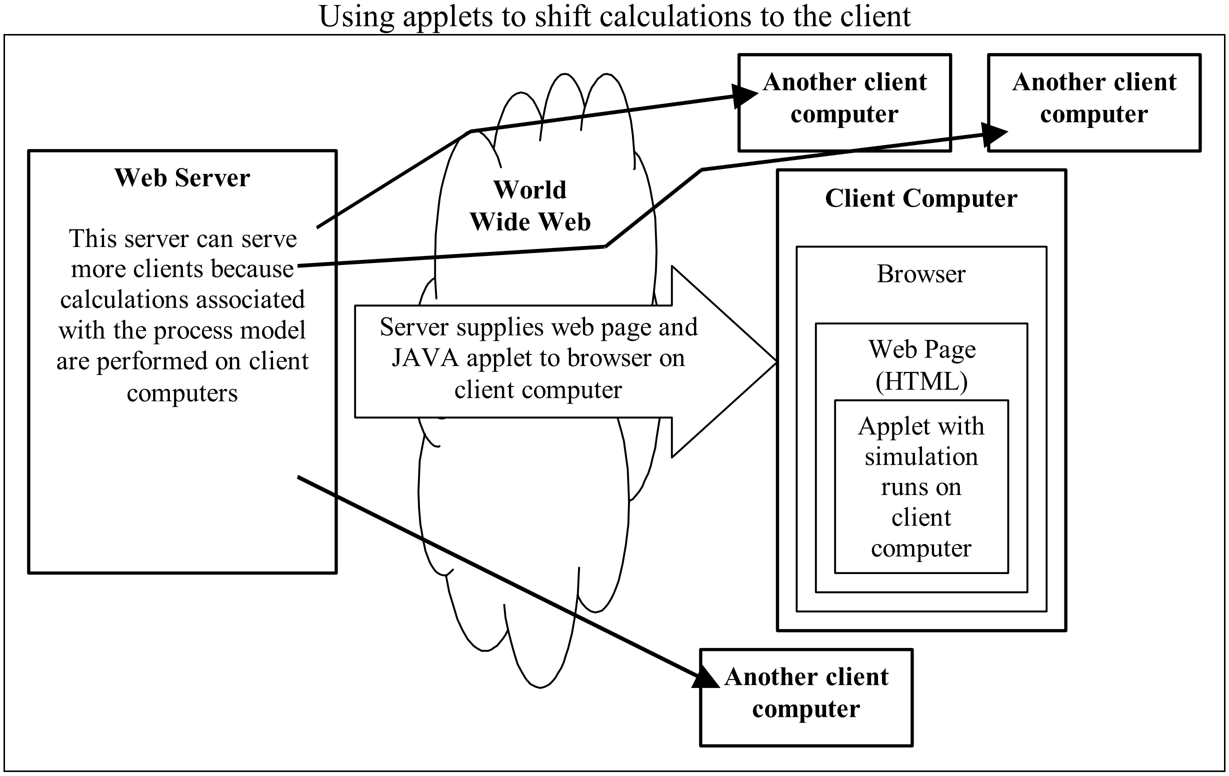
Users interact with controls in a manner similar to that used in many video games. They move the mouse cursor over the graphic representing the control (switch valve, etc.) and use the left mouse button to activate the control. To feed the reboiler before the start of a batch distillation, the feed line must be connected to it by using the mouse to drag the line to the connection (the small rectangle on the reboiler, as shown in the figure). Controls in the graphic representing the monitor (shown on the right side of the screen) are operated as in the prototype computer running Factory Floor[2]. For instance, to change a numerical value, such as feed valve position move the mouse cursor over the value (gray boxes containing numbers) until a rectangle appears around the value (shown in the figure). Clicking the left mouse button calls a dialog box (shown in the upper left of the simulated monitor screen) to enter the desired value. In this way, the look and feel of the prototype operation has been preserved as much as possible.

This module simulates the behavior of the prototype from cold start-up through distillation and shut down. When shut down is complete. The screen changes to a list of errors the module detected. If the student makes no errors, the module displays a certificate with the student's name (recorded when the student begins the module).

Implementation of VCEL on the world-wide-web

A concern in the design of VCEL was that it was to run on the school's existing server. A design goal was, therefore, that the load to the server be kept to a minimum. Obviously, a significant portion of the computer load associated with VCEL is in the interactive modules. As shown in Figure 3, the interactive portions of the modules are JAVA™ applets that run client side, thereby minimizing the server's load. .

Figure 3.
Using applets to shift calculations to the client



Applets are small applications that are called by a web page and are run by the JAVA Virtual Machine that is included in the client's browser. The JAVA language is a high level, object oriented language that is similar in syntax and organization to C++. The JAVA language and Virtual Machine have sufficient mathematical capability for mathematical simulations of engineering processes. The web server merely provides the web pages (HTML pages) and the applet.

The engineering calculations that are necessary for the module are performed on the client computer. This approach, first used by DeSteffano[3] , reduces the load on the server by shifting the task of the performing the calculations associated with the model to the client machine. As a result, VCEL runs on Widener's regular server and does not require any additional hardware. The disadvantage of this approach is that the process models must be designed to run in real time on the slowest computer likely to be used by a student (currently assumed to be a Pentium 1 running at 133Mz).

Observations and Conclusions

Table 1 shows a comparison of Fall 1999 (before VCEL was implemented) with Fall 2000 (the first semester of use). Student comments were generally favorable. 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. A significant reduction in laboratory time to run a distillation experiment is noted in the table. As noted earlier, the online module is a dynamic simulation that allows students to become familiar with the unit's operation before entering the laboratory. Additional improvement was noted in the ability of teams to perform distillation experiments. It should also be noted that distillation is a topic of a spring semester junior year course, however the experiment is performed in the senior year. Lastly, the number of equipment failures resulting from student errors also dropped. An improvement was also noted in calculations in the senior year course for heat transfer experiment and batch distillation. Improvement in the junior year course was less dramatic, both in time saving and in skills. There was a time savings of 2-3 weeks total over both courses.

Table 1
Comparison of Laboratory Classes Before and After VCEL's implementation

	Fall 1999 (Control)	Fall 2000 (using VCEL)
Overall periods saved by VCEL (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

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Prof. Nippert has been on the faculty of the Chemical Engineering Department of Widener University, Chester Pa. since 1980. He is a graduate of Lehigh University and worked for several years at Kawecki-Berylco (now Cabot Specialty Metals). His current interests include the development of web-based instructional materials for use in a variety of engineering courses. The material is contained in "The Virtual Chemical Engineering Laboratory", found at www2.widener.edu/~crn0001/VirtualLab.html. The site is open to all for examination and use. He is married and has two children.