A Comparison of Web-Based and Laboratory Learning Environments

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I. Introduction

A Web-based computer simulation of an actual laboratory experiment was developed for the MIT Laboratory classes. This virtual experiment, which we call the Web Lab, was introduced into the "Chemical Engineering Projects Laboratory" in spring 1999 and the "Chemical Engineering Process Laboratory" in fall 1999. Among the goals of these courses are to teach students laboratory, data analysis, and communication skills, including writing individual and collaborative team technical reports, making oral technical presentations, and collaborating in the laboratory in teams of three. The aim of this Web Lab was to provide a common experience early in the term in which students collect and analyze data and prepare a formal technical report with tables and figures. One feature of the virtual experiment was that students controlled the experiment and made actual readings from two graduated scales displayed on the monitor. The data collected reflected experimental errors associated with these readings as well as systematic and random errors built into the simulation software. The motive for using a Web-based environment was the notion that it would provide a means for rapidly and easily collecting data for analysis along with the convenience of running the experiment at any time and with any operating system. During its initial use in the Projects Laboratory course (enrollment of 54 juniors and seniors), the Web Lab was evaluated as a learning tool, and the following conclusions emerged[1]:

1. The ability of students to generate a technical report with the Web-based environment was as good as that of students who would use a laboratory setting.
2. When queried as to which environment they preferred, the simulated laboratory (which they all used) or the actual laboratory for the assignment of collecting and analyzing data and writing a short formal technical paper, a majority of the students preferred the use of the simulated environment to the actual laboratory environment. This preference likely results from ease of accessibility and use.
3. Students thought that the Web-based environment was suitable for gathering data and writing a report.
4. Several students expressed an interest in performing the experiment in an actual laboratory (Wet Lab) rather than on the Web because they preferred a real hands on experiment.

A more comprehensive evaluation was carried out in fall 1999 to compare use of the actual laboratory environment, which we call the Wet Lab, with use of the Web-based laboratory environment. The goal was to determine if there were any differences in preferences, performance, and ease of use between students gathering data in the Web Lab and Wet Lab. This paper describes the results from a survey given to the students following their experiences with these laboratories. Also included are statistical analysis, comments from the students, and conclusions from the results.

II. Course Description

The pedagogical methods employed in the Process Laboratory included three laboratory experiments (each of four weeks duration), the Web Lab, written reports (prepared individually and as a team), an individual oral presentation, and lectures and assignments in team formation and team maintenance. A faculty member supervised each experiment. Adjunct staff was comprised of writing practicum faculty, a team coordinator, teaching assistants, and laboratory technical staff. Because the course required a substantial amount of time, the Web Lab was designed to have the students gather data and produce a formal technical report in the shortest period of time. The students were asked to carry out the experiment, collect the data in both environments (Web and Wet), and choose one of the sets of data to use for the report. Students collaborated in using the Wet Lab experiment but worked alone in the Web Lab. They performed data analysis, graph preparation, and writing of the report individually as well.

Whatever the source of data, the following elements were required in the report: (1) description and schematic diagram of the equipment as it was used to run the experiment in the actual laboratory (Wet Lab), (2) graph of measured flowrate versus rotameter reading for use as a calibration curve, (3) table of mean flowrates at each flowmeter setting (if replicate measurements were made) and a measure of error for each mean value, (4) estimates of the parameter value and standard error of the slope and y-axis intercept of the regression line through the data, (5) identification of any random and systematic errors and explanation of possible sources for each, and (6) appendices, containing a sample calculation for each type of computation and a table of all raw data collected.

III. Wet Laboratory Description

The objective of the experiment was to calibrate a rotameter and generate a standard curve of actual flowrate versus rotameter reading. The experimental method used was a classic "bucket-and-stopwatch" procedure. The major pieces of laboratory equipment were a 20 GPH flowmeter, a three-way solenoid valve used to control flow to a graduated cylinder, and a timer with a digital display used to control the valve and measure time.

Water from a supply line with an on/off valve flowed to the rotameter, and a needle valve controlled and allowed adjustment of the flowrate into the rotameter. A three-way valve directed water flow out of the rotameter into either a graduated cylinder or to the drain. A digital timer electronically controlled the valve. When the timer was turned on, water flowed into the graduated cylinder, and when the timer was turned off, water flowed to the drain. The timer and three-way valve could be operated in manual stopwatch mode (push on to start and push off to stop flow) or in a continuous mode for a preset number of seconds. The water was collected in a 100 ml, 250 ml, or 1000 ml graduated cylinder. The students were asked to take measurements with at least two of the three graduated cylinders (one of which had to be 100 ml). They could either make replicate measurements at several rotameter settings and fit their data with a weighted least squares line or make individual measurements at eight or more rotameter settings and fit their data with an unweighted least squares line. Three identical versions of the Wet Lab equipment were set up for the students in the laboratory. Each team of three students was scheduled for a two-hour session. In order to prepare for the experiment the students were given the manufacturers' instruction manuals to read for the rotameter, the three-way valve, and the timer.

The experimental errors in the Wet Lab data included those from the following sources: (1) reading the scales on the rotameter and graduated cylinders, (2) drift and oscillations in the flowrate, since the water source for each experimental set up was shared with the other Wet Lab experiments and other users in the building, (3) residual water left in the graduated cylinder after each use, and (4) starting and stopping the timer when it was used in the manual mode.

IV. Web Laboratory Description

The Web Lab was an interactive "laboratory" which allowed students to collect data for calibrating a virtual rotameter. The data were collected with an electronic, graphical representation of the actual laboratory apparatus. A copy of the descriptive portion of the web site is contained in Appendix 1.

The Web Lab graphical representation was designed to be similar to the Wet Lab set up. The major differences between the two experiments were as follows: (1) The manual needle valve was replaced by a pair of push buttons. Depressing the plus or minus button on the monitor screen with a mouse click caused the flowrate of water to increase or decrease, respectively. (2) The timer which controlled the three-way valve could only be operated in the manual, stopwatch mode. The image was clicked once to start the timer and divert flow to a graduated cylinder and again to stop the timer and divert the water to the drain, (3) The directions for performing the Web Lab and operating the equipment were included in the web site.

The instruction page provided an overview of the experiment including pictures and descriptions of the equipment used in the virtual experiment. Instructions on how to perform the Web Lab experiment and a video demonstration of an actual rotameter experiment were provided, followed by a link to the interface for the experiment. Using the link, the students began the interactive portion of the experiment and collected data.

Two types of errors were embedded in the Web Lab program. Systematic error was introduced in the readings from the timer. Each time the program was started, a small, fixed time lag, selected at random, was built into all time readings. The magnitude of the systematic error was changed each time the graduated cylinder was changed. Positive and negative random error generated from a random number table was superimposed onto the timer readings. In addition to the errors built into the program, there were actual user errors in interpolating between the marked scales of the rotameter and graduated cylinders.

The presence of systematic and random errors could be inferred from the slope and intercept of the calibration curve for either Lab. However, the magnitudes and sources of the errors were much less obvious to the students while collecting data from the Web Lab and less easily explained in their reports. A clear perception of these errors was best gained from analyzing plots of volume collected versus time at each flowrate setting. The students were not explicitly asked for these plots, and few prepared or examined them. These difficulties in finding and explaining errors introduced the students to problems of assessing errors in the experiments they performed later in the course.

V. Description of the Fall 1999 Study

Because every student in the fall 1999 course performed nearly identical experiments on the Web and in the Wet Labs, a comparison of the two experiences was possible. A survey was given to the students to evaluate the effectiveness of each approach and its utility as a learning tool. The Web Lab was evaluated on the helpfulness of information presented, including the description and discussion of the equipment, instructions, graphical representation of the equipment components, and as an overall data collection tool. The Wet Lab was evaluated on these same elements except that the ability to use actual equipment was substituted for graphical representation. Students were asked to evaluate each environment on ease of use, including ease of access to instructions, ease of performing the experiment successfully, and ease of gathering the data, The survey asked students to rank the ease of using the interactive graphical interface of the Web Lab and the ease of using the actual rotameter in the Wet Lab. Students were then asked to rate how easy it was for them to prepare the elements required of their lab reports. In addition to these questions, students were asked about previous laboratory experience, preference of lab environment, time required for gathering data in each environment, and preference for working individually or as a member of a team.

VI. Student Demographics

The 23 students in the fall 1999 course were homogenous with respect to academic background. All were seniors, and all had previously worked in an actual laboratory environment. Only the 21 students who completed their lab reports were considered in the survey analysis. The gender distribution was eleven females (52%) and ten males (48%).

VII. Survey Data: Results and Discussion

Statistical Analysis

Many of the questions in the survey used a Likert scale (1= lowest, 5= highest). The responses were segregated according to whether students used data collected from the Web Lab or Wet Lab. These data were then arranged in a contingency table and a chi-square analysis was used to assess the null hypothesis that the distribution of responses in the two groups was not significantly different at the 5% level of significance ($P<0.05$). Rejection of this hypothesis required, with four degrees of freedom, that the chi-square value was greater than 9.49. The values of the responses of the mean $\pm$ the standard deviation in each group were tabulated in the tables that follow. Testing for differences between two means was carried out with a two-tailed t-test, also at the 5% confidence level. All data were examined by both chi-square and t-test analysis. The existence of a significant difference by one and/or the other of these analysis is indicated by the presence of an asterisk (*) next to the question.

Preferred Environment for Gathering Data

Students were asked which environment they preferred, the actual or virtual laboratory, for gathering data. Answers to this question are shown in Table 1.

Table 1. Preferred Environment for Gathering Data

Table 1. Preferred Environment for Gathering Data2. Now that you have worked in an actual Laboratory environment, which do you prefer for gathering data	Number n
(1) I would prefer to use the virtual Lab (Web Lab) to gather data for my paper	9
(2) I would prefer to work in an actual Lab (Wet Lab) to gather data for my paper	8
(3) I can't say definitively that I would prefer to use the Web Lab to gather data for my paper	4
Total	21

The nine students who preferred to gather data in the Web Lab cited ease, convenience, speed, and efficiency (e.g. the experiment was "so simple" that "nothing was gained by doing it in the [Wet] Lab"). Three also said that they did not think it was realistic, but they liked the ease, speed, and/or convenience. One perceived the Web Lab to provide more accurate data, thereby making it easier to identify errors. The eight students who preferred the actual laboratory to gather data said that the Wet Lab was more concrete and straightforward. They seemed to equate these characteristics to an environment in which it was easier to identify sources of error. However, three of the eight students who preferred the Wet Lab ultimately decided to use the data collected from the Web Lab for their reports. The four students who said that they did not have a definite environmental preference actually used the data collected from the Web Lab for their reports. They cited the Wet Lab as providing a realistic, hands-on experience, with more realistic errors. Comments about the Web Lab centered on ease of use, convenience, speed, and efficiency.

The original purpose of the Web Lab was to give students a quick and easy way to gather data from a simple experiment. The lack of clear preference for gathering data for either environment, together with several students citing the pros and cons for each environment, suggests that the Web Lab functions as well as the Wet Lab for its intended purpose, and this goal appears to have been met.

Ease of Writing Lab Reports

Students were asked to rate how easy it was for them to write their reports by considering all the elements required in the reports. The responses of all twenty-one students to this question are shown in Table 2. The column entitled "Used Wet Lab Data" refers to the six students who elected to use data collected in the actual laboratory for their reports; the column entitled "Used Web Lab Data" refers to the fifteen students who elected to use data gathered from the virtual laboratory for their reports.

Table 2. Ease of Writing the Report

12. While writing my Lab report, it was easy to: 1 = lowest; 5=highest).	Used Wet Lab Data n=6	Used Web Lab Data n=15	All Students n=21
a. Explain the objectives of the rotameter calibration	3.7 ± 0.8	4.3 ± 1.1	4.1 ± 1.0
b. Explain the procedures involved	4.2 ± 1.0	4.3 ± 0.8	4.3 ± 0.8
c. Draw a schematic diagram of the setup	4.2 ± 1.3	3.6 ± 1.3	3.8 ± 1.3
d. Draw the calibration curve	3.8 ± 1.0	3.5 ± 0.9	3.6 ± 0.9
e. Organize the data	3.5 ± 0.8	3.3 ± 1.3	3.4 ± 1.2
f. Plot the data points	4.0 ± 1.1	3.7 ± 1.1	3.8 ± 1.1
g. Generate a best-fit line through the data points	4.0 ± 0.9	3.7 ± 1.0	3.8 ± 0.9
h. Interpret the calibration curve	3.5 ± 1.0	3.1 ± 1.3	3.2 ± 1.2
i. Identify systematic error	2.5 ± 0.8	2.8 ± 1.5	2.7 ± 1.3
j. Identify random error *	2.3 ± 1.0	2.8 ± 1.5	2.7 ± 1.4

There were no significant differences in the responses except for one question which produced significantly different responses by chi-square analysis. That question, element 7j "identify random error," provided an interesting distribution of responses. All six of the students who selected the

Wet Lab thought it was difficult to identify random error (rankings of 3 or less) while the fifteen students who selected the Web Lab were nearly evenly divided between identifying random error as easy or difficult (nine rankings of 1 or 2 and six rankings of 4 or 5).

Despite student comments that one or the other of the environments was better for spotting sources of error, graders found that few demonstrated an understanding of sources of errors when writing their lab reports, irrespective of the source of the data they used. Approximately half of the students thought it was difficult to identify systematic and random error. These results have prompted the instructors to reconsider how error identification is presented to students prior to and in the Web Lab and Wet Lab environments.

The lack of a significant difference in all the other areas indicates that in the other areas both the Wet and Web Lab facilitated report preparation equally well.

Helpfulness of Web Lab and Wet Lab Elements for Writing Lab Report

The survey asked students to rate how well each of the eight elements helped them to write their report. The responses of the fifteen students who elected to use the Web Lab data and of the six students who elected to use the Wet Lab data for their reports are summarized in Table 3.

Table 3. Helpfulness of Web Lab for Writing Lab Report

5. & 6. Please rate how well the following elements of the Web Lab or Wet Lab helped you to write your report (1=lowest; 5=highest)	Used Web Lab Data n=15	Used Wet Lab Data n=6
a. Description of the experiment	4.1 ± 0.9	3.3 ± 2.0
b. Discussion of the equipment components	3.4 ± 1.2	2.5 ± 1.4
c. Instructions on how to do Web Lab	3.5 ± 1.4	2.2 ± 1.6
5d. Graphic representation of rotameter and components (Web Lab) 6d. Being able to use equipment in an actual lab environment (Wet Lab) *	2.8 ± 1.3	4.8 ± 0.4
e. Working Individually Working in a team	3.4 ± 1.1	4.2 ± 0.8
f. Data Collection Tool (how the rotameter worked)	3.2 ± 0.9	3.2 ± 1.5
g. Video	1.9 ± 1.3	

The students who used the Web Lab data gave a higher rating to the written material provided (a, b, and c), but only the description of the experiment (a) approached significance ($0.05<P<0.10$) with the chi-square analysis, The students who used the Wet Lab data rated the real experimental equipment of the Wet Lab as very helpful in writing the report, giving it a much higher score. Conversely, those who chose the Web Lab data rated the graphic representations of the rotameter and components (d) in the Web Lab much lower. This difference was significant by both chi-square and t-test analysis. The higher rating given to working as a team (e) approached significance by t-test ($0.05<P<0.10$).

Ease of Running the Experiments in Both Environments

The students were asked to rate how easy it was to run the experiment in the Web Lab and in the Wet Lab in terms of certain characteristics. Table 4 contains the results for the Web Lab, and Table 5 contains results for the Wet Lab.

Table 4. Ease of Running the Experiment in the Web Lab

7. Please rate how easy it was to run the experiment in the Web Lab (1=lowest ; 5=highest).	Used Wet Lab Data n=6	Used Web Lab Data n=15	All Students n=21
a. Ease of access to instructions	3.7 ± 1.6	4.1 ± 1.3	4.0 ± 1.4
b. Ease of performing the experiment successfully	3.7 ± 1.5	4.1 ± 1.0	4.0 ± 1.1
c. Ease of using the interactive graphic including all its components	3.7 ± 1.5	3.7 ± 1.4	3.7 ± 1.4
d. Ease of gathering the data *	4.7 ± 0.5	3.9 ± 1.0	4.1 ± 0.9

Table 5. Ease of Running the Experiment in the Wet Lab

8. Please rate how easy it was to run the experiment in the Wet Lab (1=lowest ; 5=highest).	Used Wet Lab Data n = 6	Used Web Lab Data n = 15	All Students n= 21
a. Ease of access to instructions	3.7 ± 1.0	3.3 ± 1.2	3.4 ± 1.1
b. Ease of performing the experiment successfully	3.3 ± 0.8	2.8 ± 1.1	3.0 ± 1.0
c. Ease of using the rotameter	3.0 ± 0.6	2.5 ± 1.2	2.7 ± 1.1
d. Ease of gathering the data	4.2 ± 0.8	3.1 ± 1.2	3.4 ± 1.2

In Table 4, concerning ease of using the Web Lab, responses were significantly different only by t-test for question 7d. Surprisingly, students who used Wet lab data gave the Web Lab a higher score (4.7) than did students who used the Web Lab data (3.9) for ease of gathering the data. The same question (8d) was also the only question with a significantly different response in Table 5, although there was a consistent trend that the fifteen students who used Web Lab data consistently scored the ease of use of the Wet Lab lower than did the six students who used the Wet lab data. In virtually all the cases, the Web Lab received higher scores (question 7, Table 4) for ease of use than did the Wet Lab (question 8, Table 5). This was especially pronounced for those who used the Web Lab data. The significance of differences between the responses to question 7 and 8 are summarized in Table 6 in which actual values of the confidence limits are tabulated. All differences between how those who used Web Lab data viewed the Web Lab (question 7) and Wet Lab (question 8) for ease of use were significant ($P<0.05$) or nearly significant ($0.05<P<0.10$). The means for all students ($n=21$) on the question of ease of gathering data in the Web Lab (4.1 ± 0.9) and the Wet Lab (3.4 ± 1.2) were significantly different in favor of the Web Lab ($P<0.05$). Ease, speed, and convenience of use were the original objectives for creating the Web Lab, and the data indicate that these goals were met.

Table 6. Significance * of Differences between Responses to Question 7 (Table 4) and Question 8 (Table 5)

Data Used		8a			
		Wet Lab		Web Lab	
		χ^2	*t*	χ^2	*t*
7a	Wet Lab	-	-	-	-
	Web Lab	-	-	-	0.09

Data Used		8b			
		Wet Lab		Web Lab	
		χ^2	*t*	χ^2	*t*
7b	Wet Lab	-	-	-	-
	Web Lab	-	0.09	0.05	0.002

Data Used		8c			
		Wet Lab		Web Lab	
		χ^2	*t*	χ^2	*t*
7c	Wet Lab	-	-	0.02	-
	Web Lab	-	-	0.08	0.03

Data Used		8d			
		Wet Lab		Web Lab	
		χ^2	*t*	χ^2	*t*
7d	Wet Lab	-	-	0.09	0.07
	Web Lab	-	-	-	0.06

*Numbers represent confidence limit (α) where $P<\alpha$.

Usefulness as Tools and Time Required

Students were asked to rank the laboratory environment they used for the data in their report. No significant difference was observed (Wet Lab = 3.7 ± 1.0, Web Lab = 3.6 ± 0.9). There was no significant difference between the mean of the grades for the report received by the students who used the Wet Lab or Web Lab data.

The students were asked to estimate the time required to collect data in each of the environments. Responses (1.3 hrs) were identical for both labs. The original goal for the Web Lab was to have a student gather data for less than an hour. It is believed that spending less than one hour gathering data is attainable with minor modifications to the program.

Gender Differences

Females with higher grade point averages (GPA) entering into the course had higher writing and technical grades on their reports. They preferred to use the Web Lab data for their reports. For males, there was not a significant difference in grades or preference for sources of data based on GPA. There were no significant differences between males and females in GPA entering the course.

VIII. Conclusions

By far the largest significant difference was that most students perceived the Web Lab as easier to use in all aspects. With t-values of 0.09, 0.002, 0.03, and 0.06 for comparing the Web Lab and Wet Lab responses on the four ease of use questions (see Tables 4, 5, and 6), the differences were significant ($P<0.05$) or nearly significant ($0.05<P<0.10$). The one negative reaction to the Web Lab was that the graphic representation of equipment components was not rated as highly as using equipment in an actual lab for help in writing a lab report. Students using Web Lab data for their reports ranked the graphic representation of the rotameter at 2.8 ± 1.3 as being helpful while students using Wet Lab data ranked being able to use equipment in an actual lab environment at 4.8 ± 0.4. Still, using the Web Lab was perceived as easier than using a real rotameter. Also, the "hands on" experience of using an actual laboratory was available in the remainder of the course.

The authors conclude that the Web Lab was easier to use, the Web Lab and Wet Lab were preferred equally by the students (nine students preferred the Web Lab, eight students preferred the Wet Lab, and four could not give a definitive answer, but cited pros and cons of each), most students (fifteen) chose to use data gathered in the Web Lab for their reports, and the source of data used for the report had no effect on performance. Thus, we conclude that the Web Lab can be substituted for an actual laboratory experience as a pedagogical tool for teaching students data analysis and technical report writing.

Bibliography

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Biography

BONNIE D. BURRELL
Bonnie Burrell is a lecturer in the Chemical Engineering Department at MIT. She is presently teaching team development to chemical engineering students. Since completing the pilot project started in 1997 she has been developing a curriculum in teamwork training and communication skills that is being integrated into the chemical engineering curriculum from the undergraduate to the graduate course level.

CLARK K. COLTON
Clark K. Colton is a Professor of Chemical Engineering at MIT. Dr. Colton has carried out extensive research and has approximately 200 publications in chemical engineering fields, especially bioengineering, and he has won numerous awards for his research. He is currently in charge of the Chemical Engineering Projects Laboratory. He developed a pilot project to introduce team building skills into the chemical engineering Projects Laboratory in collaboration with Bonnie Burrell, and he has continued to work with her to expand team work and communication skills training into other undergraduate and graduate subjects.

WILLIAM DALZELL
William Dalzell is a lecturer in the Chemical Engineering Department at MIT. He received his Ph.D. from MIT. His expertise is in new product development, heat transfer and laboratory project curriculum development. He has been working with Clark Colton, Bonnie Burrell, Jack Howard, Nishikant Sonwalkar, and Rae Jean Wiggins on the development of educational learning tools to be integrated into the laboratory courses in the Chemical Engineering Department.

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Michael Kutney is a Ph.D. candidate in the Chemical Engineering Department working on his thesis. He is currently a teaching assistant for the Chemical Engineering Projects Laboratory course.

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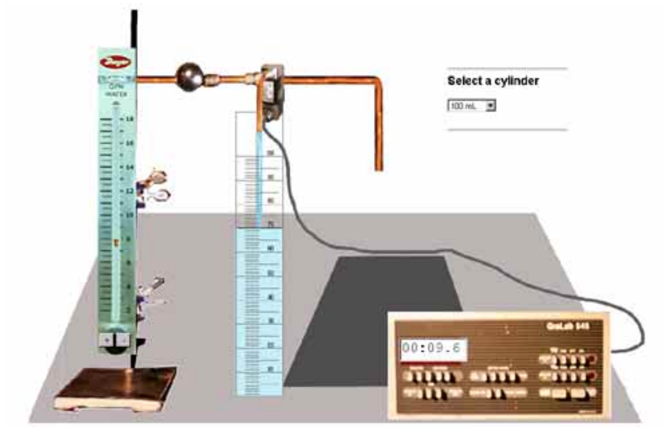
Dr. Nishikant Sonwalkar is the founding Director of the Hypermedia Teaching Facility at MIT. He has extensive research and development experience in hypermedia authoring, advanced scientific visualization, database management systems, and computer simulation. He is the co-author of MIT's first Fluid Mechanics Hypercourse CD-ROM and is regarded as a leading expert in the application of computers in education. Dr. Sonwalkar invented the conceptual model of the "Curricular Hyperweb" and implemented it using the Hypermedia Instruction and Teaching Environment (HITE), a framework for the delivery of hypermedia education over the World Wide Web. He is a consultant to many multi-national corporations on Intranet and Internet strategy. He holds Ph.D. in "Interface Mechanics" from MIT. Besides hypermedia in education, Dr. Sonwalkar is actively involved in the Molecular Dynamics simulations and Raman Spectroscopy research related to the advanced material interfaces. He invented the combined molecular dynamics (MD) and Raman Spectroscopic methodology for designing atomic scale interfaces.

RAE JEAN N. WIGGINS
Rae Wiggins is an Instructional Designer and a Formative Evaluator of Educational Technologies at MIT's Hypermedia Teaching Facility. She earned her ED.M. in Technology in Education from the Harvard Graduate School of Education. She earned an M.S. in Library and Information Science from Simmons College. Rae's evaluation work includes formative evaluations for an online course in Chemical Hygiene, a distance education course on art and architecture, a training program in online searching, a television program on K-12 science education reform, and consulting on an evaluation of a Web-based Chemical Engineering Lab. Rae is also a member of the evaluation team for the Physics Interactive Video Tutor (PIVOT) project at MIT. In addition to her evaluation work, Rae designs multimedia and educational software and is co-teaching a course on the topic of educational software design at the Harvard Graduate School of Education in the spring 2000.

APPENDIX # 1

Chemical Engineering Rotameter Calibration

OVERVIEW



A common problem faced in chemical engineering research as well as in industrial process plants is calibration of flow meters. It is a classic problem in which one assesses the accuracy of results and precision of equipment involved in an experiment by using an independent set of standards.

Description of the Experiment:

You are asked to calibrate a flow meter called a rotameter using a "bucket and stopwatch" procedure. Following the experiment you will analyze the data, plot the results, and write a brief technical report.

You may calibrate the flow meter starting at low flowrates or high flowrates in any order you wish. You should measure the volume collected in the graduated cylinder for the elapsed time indicated by the electronic clock at each flow meter setting. You will plot the data as measured flowrate in gallons/hour versus meter reading in gallons/hr. You should put error bars on the data points and fit a weighted regression line through the data.

You will then write a formal technical report describing the purpose of your calibration, the approach you used, and your results. You should note any observed errors or biases and discuss how these might have arisen. The exact requirements for the report are given in class.

EQUIPMENT

The following is a list of components used in the experiment:

- Push button flow regulators
- On/Off Valve
- 18 GPH Rotameter. Manufactured by Dwyer Instrumental, Inc., Michigan City, Indiana. Catalogue No. RMC-134-SSV
- Three-way solenoid valve to control flow from the rotameter. Manufactured by Burkett Co., Miami, Florida. Model W37UP
- Graduated cylinders
- Electronic Timer. Gralab Timer Model 545 Manufactured by Dimco-Gray Co., Centerville, Ohio.

Push Button Flow Regulators


Increase **Decrease**

These buttons control and regulate the flow of water through the system.

The button labeled "+" increases the flowr ate through the system. The button labeled "-" decreases the flowrate through the system.

Clicking either button will adjust the flow in incremental steps whereas depressing either button will adjust the flow continuously.

The push button flow regulators visible on the screen actually replace a needle valve built into the bottom of the flow meter. Water is supplied to the back of the flow meter from an elevated storage tank. For clarity, your diagram of the equipment should have the needle valve represented separately in series with the flowmeter.

On/Off Valve

The on/off valve is visible on the screen and is located between the top of the rotameter and the three-way solenoid valve. This valve switches the flow of water from off to fully on at the maximum flowrate possible through the system. In this web laboratory, the on/off valve is on at all times.

Flowmeter

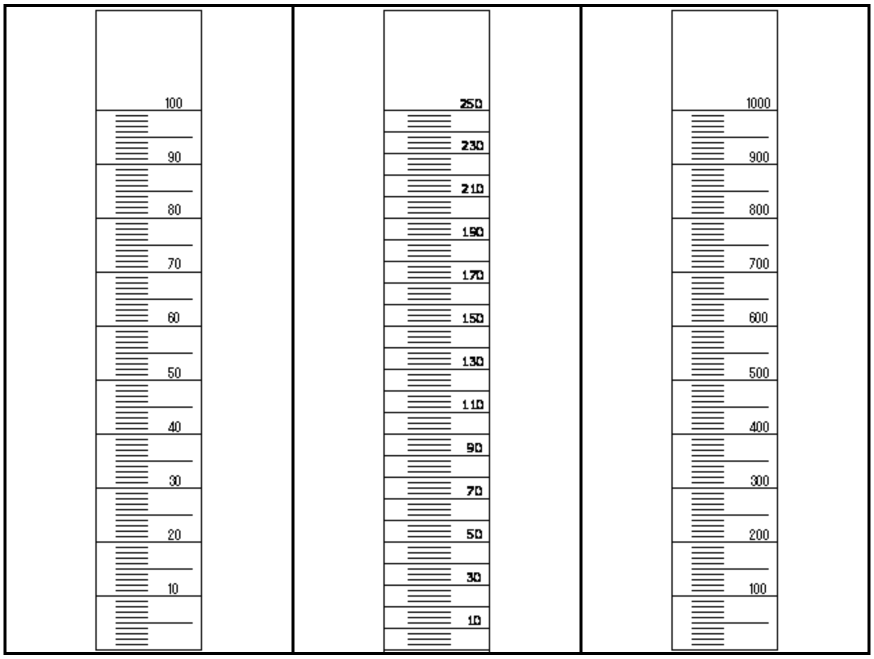
A class of flowmeters, called area meters, consist of devices in which the pressure drop across the instrument is constant, or nearly so, and the area through which the fluid flows varies with flowrate. The area is related, through proper calibration, to the flowrate.

The most important area meter is the rotameter. It consists essentially of a gradually tapered glass tube mounted vertically in a frame with the large end up. The fluid flows upward through the tapered tube and suspends freely a float (which actually does not float but is completely submerged in
the fluid). The float is the indicating element, and the greater the flowrate the higher the float rides in the tube. The entire fluid stream must flow through the annular space between the float and the tube wall. The tube is marked in divisions, and the reading of the meter is obtained from the
scale reading at the reading edge of the float, which is taken at the largest cross section of the float. A calibration curve must be available to convert the observed scale reading to flowrate. Theory predicts that for a rotameter, the relation between meter reading and flowrate is approximately linear. The meter readings on the rotameter were put there by the manufacturer. One goal of your experiment is to determine if they are correct.

Three-way solenoid valve

The three-way valve directs the water to flow from the rotameter to either a graduated cylinder or the drain.

Graduated cylinders



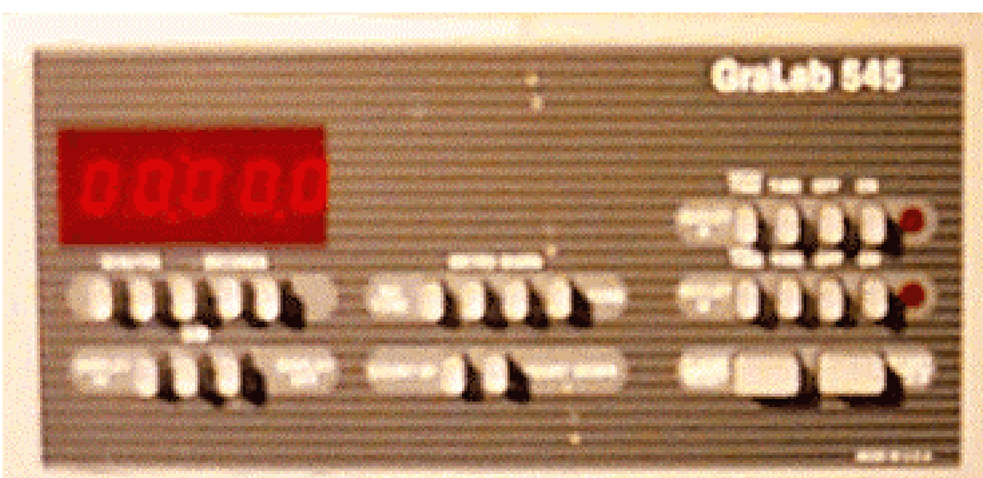
100mL 250 ml 1000 ml

The cylinder is used to collect water. It has graduation marks which indicate the volume of water collected in milliliters.

There are several graduated cylinders which are available for this experiment. You should prepare a complete calibration curve with at least two cylinders.

(Note: even though the cylinders are the same size graphically, they are different volumetrically.)

Electronic Timer



The electronic timer is connected to the three-way solenoid valve and controls the direction of flow within the valve. It is also used to determine the elapsed time during which water is flowing into the graduated cylinder. The timer reads in minutes and tenths of a second. (mm:ss.s)

Start/Stop Button

The timer is activated by pushing the button at the bottom right of the timer unit indicated by an arrow in the diagram. The timer starts once this button is pushed. Depressing the same button again stops the clock.

INSTRUCTIONS

Before the experiment can be started, you must select a particular cylinder from the pull-down menu.

Once the cylinder image is visible, you are ready to begin.

At this point, you must turn on the flow through the system by pushing the button marked "+" . Upon doing so, you will notice that the bob in the flowmeter starts to move. That is the indication that water is flowing through the system. Set the flowrate to a desired setting in order to collect water at that given flowrate. You will notice that depressing either button will cause the float to move continuously whereas clicking the button causes incremental movements.

When you first initiate the flow, water flows through the three-way valve into the sink. To reroute the water to the cylinder, you must push the start button on the timer unit. Doing so will also start the timer.

After water starts collecting in the cylinder, you will need to stop the flow at some point. The flow of water to the cylinder can be stopped by pushing the same button on the timer unit. You can make one or multiple measurements as you fill the cylinder. To repeat the experiment with the same cylinder you can press "BACK" on your browser and then "GO TO EXPERIMENT" or press "SHIFT" on your keyboard and "RELOAD" on the browser.

Repeat the measurements at least two or three times at five or more flowrates with each cylinder.

PREVIEW THE LAB

GO TO THE EXPERIMENT