AC 2008-1351: IMPLEMENTING INQUIRY-BASED EXPERIMENTS IN A FLUID SCIENCE LABORATORY CLASS

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Abstract
Two inquiry-based laboratory exercises are incorporated into a laboratory section of a fluid mechanics class for third year Civil Engineering and Mechanical engineering students. The laboratory section also involves four other conventional laboratory exercises. The inquiry-based exercises are designed to confront student misconceptions and to develop the ability of students to use qualitative reasoning. Student learning gains and changes in attitude were assessed for 73 of the 119 students in the class who volunteered to participate in the research project. The study group completed background surveys and surveys on attitudinal change during the academic term in which the laboratory exercises were completed. Preliminary analysis of the surveys indicates that student attitudes toward laboratory work did not shift significantly. Students are familiar with conventional laboratory exercises in which their activity in the laboratory is largely confined to observing the equipment and recording data. The inquiry-based exercises require more active participation and analysis of results while the experiment is being conducted. The survey data and observations of the students in the laboratory suggest that additional effort is necessary to acquaint students with the inquiry-based approach. It is not clear; for example, to what extent student preference for conventional exercises is due to lack of experience with the inquiry-based approach.

Introduction
Laboratory-based classes and lecture classes with a laboratory section provide hands-on learning experiences to engineering students. The equipment used in the laboratory exercises can vary from simple items on sale in a hardware store[1-3], to complex and highly engineered systems like engines[4]. The nature of the student activity can also vary. In some cases, students make measurements from a highly prescribed protocol on equipment that has been tuned to give a predictable result. On the other extreme students can be given open-ended measurement assignments in which deciding what to measure, and designing the experimental procedure is part of the exercise[5].

This paper describes our experience in implementing two inquiry-based laboratory exercises in a laboratory class that also consists of conventional laboratory exercises. We define a conventional experiment as a laboratory exercise focused on collection and analysis of data and the written presentation of the results. In a conventional exercise the students spend their time in the laboratory following prescribed steps to record sensor readings while the experiment is running. There is little or no analysis before the students leave the laboratory. The bulk of the effort is spent on data reduction and technical writing. At some other date, typically one week after making the measurements, students turn in a report on their measurements. Their report is written in the style of a scientific paper.

Inquiry-based learning experiences attempt to present authentic challenges or tasks to the student as part of the assignment[6, 7]. In an inquiry-based exercise, the students are expected to choose a method of solving a given problem, not merely execute a predefined series of steps. Our experiments use *guided*-inquiry, a compromise between open-ended inquiry and the recipe-like approach to conventional exercises. In the guided-inquiry approach, students are presented with a question to answer along with a procedure and equipment to be used in obtaining the answer. In our approach to guided-inquiry, the purpose of the exercise is to solve a problem in the laboratory. Students do not leave the laboratory with an assignment to complete additional analysis of their data, though that is not precluded by inquiry-based pedagogy. The inquiry-based exercises use relatively simple hardware and data acquisition systems that further simplify the data collection tasks. The hardware and exercises are designed to allow the students to focus on core concepts, not on the complexity of running an experiment. Students complete worksheets during the class and turn the worksheets in for grading before leaving the laboratory. There is no lab report. Inquiry-based pedagogy neither requires nor prohibits the assignment of a report. We simply designed our research to focus on the difference between learning by doing (in the laboratory) and learning by watching in the laboratory and writing a report at home.

Our guided-inquiry exercises are also designed to cause students to confront their own misunderstandings about the system being studied. In order to focus attention on misperceptions, students are asked to make predictions about system response immediately before making measurements of the system response. It is much harder for students to rationalize a direct measurement that contradicts their preconceptions, than it is for the students to ignore a theory that contradicts their own belief about a physical system.

Another goal of the inquiry-based exercises is to help students develop qualitative reasoning skills. Predictions of system response are more reliable when students can use an engineering model of system behavior. Qualitative reasoning involves the use of models (e.g. formulas, differential equations, force and energy balances) without necessarily have quantitative data for all terms in the formula. For example, by invoking the Bernoulli equation one concludes that the pressure increases when the velocity decreases.

Both the nature and the timing of student effort are very different in the two types of laboratory exercises. In the conventional laboratory exercise, the effort primarily involves data analysis and writing and that effort is concentrated outside of the laboratory when students analyze the data and prepare their report. In the inquiry-based laboratory exercise, students spend all of their effort manipulating the equipment and performing analysis to answering questions on a worksheet. All the effort occurs in the laboratory.

In this paper we report on the process of and the results from implementing inquiry-based experiments in a fluid science laboratory class. We describe the pedagogical framework; the two experiments created, and provide a preliminary assessment of the outcome. The work is part of a two-year, NSF-funded project called the *Engineering of Everyday Things* (DUE-0633754). A overview of the project is described in an earlier paper [8].

We also report on challenges that have arisen in implementing the inquiry-based exercises. We lack control over the class curriculum because our laboratory exercises are incorporated into an existing course taught by an instructor who is not part of our research team. Our colleagues are supportive and interested in this work. However, because the inquiry-based approach is unfamiliar, we need to provide orientation on goals and pedagogy to the faculty as well as the students.

Goals of Research

The primary goal of this research project is to develop inquiry-based laboratory exercises to augment courses in the thermal and fluid sciences. Our hypothesis is that the inquiry-based pedagogical model will improve learning of core concepts and increase student appreciation of laboratory work. The focus of this paper is on two exercises that were introduced into an existing laboratory section of a required fluid mechanics course for third year students.

To achieve the larger goals, the project has several specific objectives. To engage student curiosity and interest, the experiments use equipment or technology that is either simple or easy to understand. We believe that students are more likely to reveal their misconceptions when the experimental apparatus is familiar or at least not too complex. Where possible, the laboratory exercise is designed force students to make an either-or choice in their prediction of system response to an input. Those binary choices provide a clear distinction between understanding the course material and not understanding it.

The laboratory exercises use low-cost data acquisition (DAQ) devices and ready-to-run LabVIEW Virtual Instruments (VI) that enable students to gather data without worrying about connecting sensors or developing data acquisition software. Those tasks are important, but we presume that students who are skilled at manipulating cell phones, computers, and MP3 players are also predisposed to using software and hardware without reading the manual first. We also assume that students will take a follow-up class on sensors and DAQ, and that the preliminary exposure via the inquiry-based exercises will motivate their interest in sensors and DAQ.

Finally, we aim to increase the utility of the laboratory exercises in a variety of settings. The exercises are being developed for and tested in courses in mechanical and civil engineering, and for mechanical and electrical engineering technology. The exercises are also being developed for and tested in classes that do not have a conventional laboratory section. In this paper we describe the implementation of the experiments in a class with a lab section.

Inquiry-Based Pedagogy

Prince and Felder provide an overview of learning experiences based on a constructivist model of knowledge[6]. They describe inquiry-based learning as "instruction so that much learning as possible takes place in the context of answering questions and solving problems". A guided-inquiry approach provides more direction to students than a pure inquiry-based approach.

Inquiry-based exercises and conventional laboratory exercises can differ in the degree of student preparation necessary before conducting the measurements. Often the explicit goal of a conventional laboratory exercise is to confirm a theory presented in a lecture. Thus, for a conventional laboratory exercise, it is very important for students to have seen and worked with the theory before coming to the lab. In contrast, in an inquiry-based laboratory exercise, students can be asked to make observations of phenomena for which they do not have theoretical models. In that case, the laboratory exercise is one of authentic discovery and synthesis. The inquiry-based approach puts more responsibility on the students as they work in the laboratory.

One of the desirable consequences of guided-inquiry exercises is that students are discouraged from racing through the measurements. The inquiry-based laboratory exercises require the students to make predictions and verify those predictions with measurements. The data collection process is interspersed with analysis and interpretation. An undesirable consequence of inquiry-based pedagogy is that students can become frustrated by the unfamiliar approach and the extra demands of active participation it places on them[6]. This displeasure is shown in the survey results presented later in this paper.

To deal with the extra demands on student time and attention during the inquiry-based exercises, the current version of our experiments have been simplified somewhat from the initial implementation. In some cases, fewer data points were recorded to determine a trend. In others, the scope of the experimental procedure was reduced.

The laboratory measurements in our inquiry-based laboratory exercises are designed to expose student misconceptions. The students are asked to make a prediction that exposes their thinking. This is followed with a direct measurement that confirms a correct model or shows the error of an incorrect model.

Finally, our inquiry-based experiments are designed to teach students to apply qualitative as well as quantitative reasoning. During the laboratory exercises, and on the pre and post-lab quizzes, students are asked to predict trends in the measured data before that data is collected. Use of qualitative reasoning is encouraged because the experiments are designed to allow trends in the dependent variable(s) to be readily measured.

The Laboratory Exercises

The two laboratory exercises described in this paper were performed as part of a weekly laboratory section in a required fluid mechanics course for third year students in Civil and Mechanical Engineering. Altogether, the students performed six laboratory exercises that were graded. Four exercises were conventional, and two were inquiry-based.

Tank Filling

The objective of the tank filling exercise is to develop in students a solid conceptual understanding of the hydrostatic equation. In particular, the experiment confronts the misconception that in a stationary fluid the pressure at a given depth is determined by the weight of the water above that depth. The measurements and the apparatus are very simple. It is possible for students to complete the exercise with only a basic knowledge of physics and without any prior exposure to fluid mechanics.

Figure 1 shows the apparatus for the tank-filling experiment. Two cylindrical tanks made of acrylic are placed side-by-side on the workbench. One tank has a uniform diameter and the other has a step change in diameter. Both tanks have a pressure transducer (Omega PX181B-001G5V) on the side at a distance *H* from the base. The pressure transducer output voltage is recorded using a low-cost DAQ (National Instrument USB-6008), which sends the digitized data to a computer running a VI written in LabVIEW.

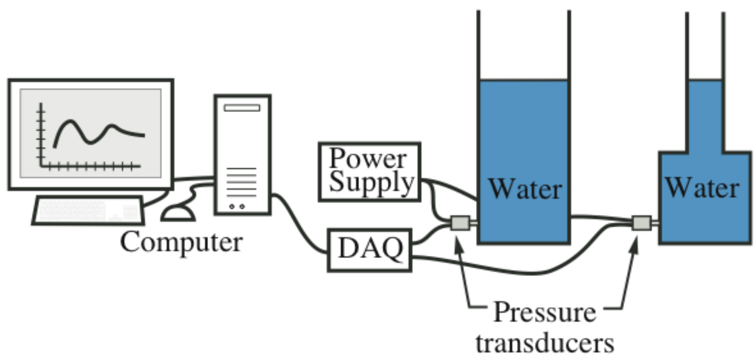

Figure 1: Apparatus for the tank filling laboratory exercise.

The assignment in the tank-filling exercise is to determine the "relationship between pressure measured by the transducers, and the amount" of water in the tank. Choice of the word "amount" instead of "depth" is intentional because we want the students to find out whether the volume of water or the depth of the water determine the pressure at the bottom of the tank. The primary learning objective of this experiment is that students understand that the shape of the tank does not matter in determining the pressure distribution.

The students fill the uniform tank to different depths and record pressure transducer readings from the VI display on the computer. The transducer output is in volts (on purpose), so that students need to convert the signal to a pressure using the linear calibration curve that we provide to them. After the first data set is collected, the students answer a few quantitative questions regarding the data. Next the students repeat the tank filling measurements for the tank with the step-change in diameter. Data recorded for both the step tank and the uniform tank are used to answer several qualitative questions. Students are then asked to plot the combined measurements of pressure versus depth. From that plot the students are asked to determine the value and physical significance of the slope, which is the specific weight.

Similar tank experiments have been used in class demonstrations, science museums, and by other others. For example, the supplemental material to the textbook by Munson, Young and

Okiishi includes a video of water draining from three holes in a two liter soda bottle[9]. Libii[10], and Libbi and Faseyitan[11] describe a tank-draining experiment where the drain orifice is at the bottom. Saleta et al. use a configuration similar to our apparatus[12].

Sudden Expansion

The objective of the sudden expansion exercise is to investigate the relationship between pressure drop and area change for the flow air through a sudden expansion in a circular duct. Students measure the relationship between the pressure across the sudden expansion and the magnitude of the centerline velocity immediately downstream of the sudden expansion.

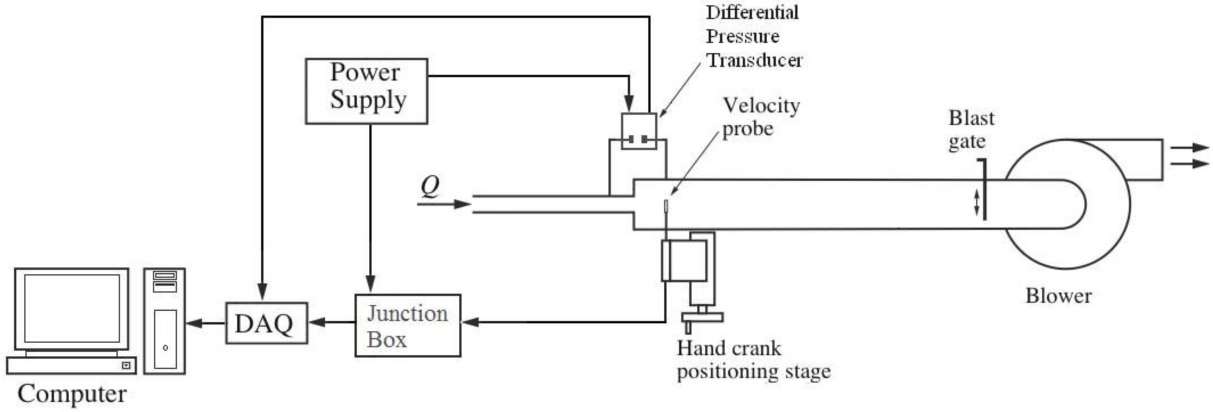

Figure 2: Apparatus for the sudden expansion exercise.

Figure 2 shows the main components of the apparatus for the sudden expansion exercise. A blower draws air through a duct constructed from acrylic tubing of two diameters. The inlet end of the duct is open to the laboratory. The longer section of tubing with the larger diameter connects the inlet section to the blower. The transition from the smaller diameter duct to the larger diameter duct is abrupt. The flow rate through the duct is controlled by adjusting a blast gate. The flow rate can also be changed by selecting one of two speeds for the blower motor.

The pressure change across the sudden expansion is measured with a differential pressure transducer (Omega PX653-0.5D5V). The air velocity is measured with a thermal anemometer (TSI Model 8455) mounted on a manual positioning stage (Velmex A2509Q2-2.5) that allows the anemometer to be moved to different radial positions across the larger duct. The velocity sensor is connected to a signal conditioner. A DAQ (National Instruments USB 6008) digitizes the output of the anemometer and pressure transducer. The data is displayed on the computer with a VI written in LabVIEW.

Although the flow through the sudden expansion is nominally steady, the VI updates the display with large samples (150 points) of velocity and pressure readings taken at 50 Hz. The sample size and rate are adjustable, of course, but we found that exposing these data acquisition parameters to the students was neither necessary nor conducive to their understanding of the basic operation of the equipment. The VI clearly shows the fluctuations in the velocity and pressure, but the sampling rate and sensor bandwidth are not high enough to capture a true turbulence signal. Each sample from the velocity and pressure sensors is displayed as a function of time and as a histogram. The histograms provide an opportunity to talk about the meaning of an average and conversely point out that computing the average is not always meaningful. When a sample of 150 readings shows histograms with nicely shaped (normal-like) distributions, the students click a virtual button on the screen to record the data to disk for later processing.

The assignment in the laboratory exercise is to measure the pressure difference across the sudden expansion and to relate the pressure difference to the prediction of the Bernoulli equation. Before turning on the device and recording any data, the students are asked to predict the sign of the pressure difference: does the pressure increase or decrease in the flow direction?

After completing the preliminary analysis, the apparatus is turned on and the students measure the centerline velocity downstream of the expansion and the pressure difference (pressure rise) across the sudden expansion at four flow rates. The guided-inquiry worksheet guides students through additional analysis with the newly collected data. In particular, students are asked to compare the measured pressure rise with the pressure rise obtained with the Bernoulli equation. Analysis with the Bernoulli equation points out the misconception to students who first predicted that the pressure must *decrease* in the flow direction. Comparison with experimental data is startling: the measured pressure rise is several hundred percent smaller than the pressure rise predicted by the Bernoulli equation.

The sudden expansion exercise provides an opportunity to address two student misperceptions. The first is the assumption that fluid pressure must always decrease in the direction of flow. The second is that Bernoulli's equation can always be applied. In a laboratory exercise for the following course (not discussed in this paper), students use the sudden expansion apparatus to measure the minor loss coefficient for the sudden expansion and compare it with the design formula for the minor loss coefficient.

Assessment

Quizzes, exam questions, and surveys were developed to measure student learning gains and changes in attitude toward laboratory work. The assessment results reported in this paper are a preliminary analysis of our first large cohort of students. The assessment results point to obvious improvements in our assessment instruments and methodology.

Assessment Methodology

The research was conducted at a large urban university located in the center of a major metropolitan area. The university has a mission of access: many students work part time, and many are not recent high school graduates. We solicited 73 volunteers to participate in our study from the entire population of 119 students originally enrolled in the course. The procedures for soliciting volunteers and protecting their anonymity were approved by the PSU Human Subjects Research Review Committee. By volunteering for the study, students allowed us to record and track their individual scores on quizzes, exams, and laboratory exercises. In the remainder of this paper the volunteers are referred to as the *study group*. Since all students performed the same experiments, there was no control group.

Three assessment instruments were administered only to the study group.

1. A Background Survey collected information on the students' age, ethnicity, previous post-secondary educational experiences, work experience, academic major, and estimated GPA. The complete background survey is provided in Appendix A.
2. A Pre-Study survey of attitudes obtained a self-assessment of student learning styles, laboratory skills, attitudes toward laboratory work. The Pre-Study Survey is provided in Appendix B.
3. A Post-Study survey of attitudes used many of the questions from the Pre-Study survey and some additional questions aimed at determining the students' experience in the laboratory during the term. The Post-Study Survey questions that were not on the Pre-Study survey are listed in Appendix C.

The average age of the study group is 26.8. Two thirds of the study group has a job and work an average of 18.5 hours per week. The high fraction of working students is consistent with the urban location and university mission of access. The study group consists of 58 percent civil engineering majors, 38 percent mechanical engineering majors and 4 percent from other majors.

For each of the two laboratory exercises all students in the class completed a pre and post-lab quizzes in addition to a guided-inquiry worksheet.

1. The Pre-lab Quiz assesses the students' knowledge before the laboratory exercise, and in particular their misconceptions related to the laboratory material. The quiz consists of one or two (depending on the experiment) very simple qualitative reasoning questions. Students are given points for completing the pre-quiz, but are not graded for correctness of their answers.
2. The Laboratory Exercise consists of a several page worksheet. The goal of the exercise is to reinforce core concepts by applying direct observation and simple analysis. The laboratory exercise was also designed to further expose and correct misconception that the student might have.
3. The Post-lab Quiz assesses whether students' misconceptions persisted after completing the laboratory exercises. As with the Pre-lab Quiz, students are given points for completing the pre-quiz, but are not graded for correctness of their answers.

In addition to the laboratory exercises, the research team worked with the course instructor to design one question each for the midterm and final exams. These questions were designed to measure whether students learned the concepts addressed in the laboratory exercises.

Volunteer Effect

The volunteer effect is a bias that occurs in social science research when the subjects are selected by their willingness to volunteer to participate[13, 14]. Table 1 and 2 show that the study group (who volunteered to complete surveys) usually has higher average laboratory and exam scores than the students the non study group who chose not to complete the additional surveys. Thus, we can conclude that there is a volunteer effect and that conclusions in this paper can only be applied to the study group.

Table 1: Differences between pre-test, post-test and laboratory exercise scores for students not in the study group and students in the study group.

	Tank-Filling Laboratory Exercise			Sudden Expansion Laboratory Exercise		
	Percentage making no errors in the Pre-Lab Quiz	Worksheet Average Score Out of 30	Percentage making no errors in the Post-Lab Quiz	Percentage making no errors in the Pre-Lab Quiz	Worksheet Average Score Out of 30	Percentage making no errors in the Post-Lab Quiz
Non Study Group (n = 30)	40.0 %	26.1	93.3 %	67.9 %	27. 9	82.1%
Study Group (n = 73)	60.3 %	26.8	98.6 %	75.0 %	28.04	72.1%

Table 2: Average scores on the exam questions that focused on concepts related to the tank filling (midterm) and sudden expansion (final) exercises.

	Midterm Exam Question	Final Exam Question
	Average Score Out of 20	Average Score Out of 10
Non Study Group (42)	14.8	4.9
Study Group (70)	15.8	6.9

Survey Scoring

As shown in Appendix B and Appendix C, survey responses were indicated on a Likert scale. For each question with a Likert scale response, the average response was calculated from

$$R = \sum_{i=1}^{5} r_i n_i \Big/ \sum_{i=1}^{5} n_i \qquad (1)$$

where r_i is the numerical value of the response corresponding to one of the following assigned numerical values of the Likert scale (Strongly Agree = 5, Agree = 4, Neutral = 3, Disagree = 2, and Strongly Disagree = 1) and n_i is the number of students with response r_i. There are five terms in the numerator and denominator of *R* because there are five possible responses (five bins) for each question.

The value of *R* is calculated for each question on each survey. For pairs of surveys by an individual student, an aggregate change in response was computed from

$$D = R_{post} - R_{pre} \qquad (2)$$

where *D* is the difference in response for each question, R_{post} is the average response on the post-study survey, and R_{pre} is the average response on pre-study survey.

For example, Survey Item 31 states, "Laboratory exercises help students learn engineering concepts". Figure 3 shows the histograms of responses for the pre-study and post-study surveys, and the change in responses. For this question, R_{post} =3.90, R_{pre} = 3.86, and D=0.4. The aggregate numerical values indicate that there was a small shift in attitude toward agreement with the statement. We are not prepared at this point to say whether the change is significant or whether it is attributable to participation in the study.

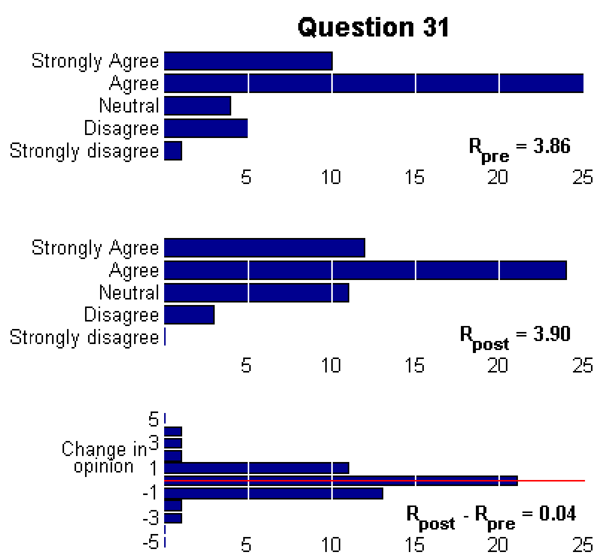

Figure 3: Histograms of responses to survey item 31, "Laboratory exercises help students learn engineering concepts".

Observations of Students in the Laboratory

The laboratory class was scheduled for one hour and 15 minutes, but it usually took an hour and 30 minutes to complete the inquiry-based exercise. That time does not include an extra 15 minutes in the first laboratory session to introduce the study, fill out the consent forms, and complete the pre-study surveys.

Instead of following the laboratory exercise worksheet step by step, several groups, skipped around because they thought it would be faster to get all the raw data first then answer the analysis/discussion questions. This behavior shows that years of practice with conventional laboratory exercises create expectations and attitudes that interfere with inquiry-based exercises. Although groups thought that changing the order of the exercises would shorten their time in the laboratory, our observation notes do not show any significant reduction in time to complete the inquiry-based exercises for those students who did not follow the instructions for the exercise.

Students doing the inquiry-based exercises were aware that other groups in the lab completed the conventional lab exercises in less time. This was apparent during the first experiment (the tank filling exercise) because another conventional exercise was conducted in the same room at the same time as the inquiry-based exercise. The conventional exercise took 45 minutes to "complete", while the inquiry-based exercise took an hour and a half. However, "completion" in the laboratory meant only that all of the data was recorded. Students doing the conventional exercise would then spend substantially more time at home analyzing the data and writing a report. Some students working on the inquiry-based exercise would comment that the other group was "done" but that they were still working on this "longer" inquiry-based exercise. To be fair, this attitude persisted only with some students, and it was largely corrected when instructors pointed out that the students doing the inquiry-based exercise did not have to write up a laboratory report.

When they performed the tank-filling exercise, some students had not completed all the lectures and homework that provided the theoretical background. This was especially true for the students in the first week of class. The sudden expansion experiment was performed at the end of the academic term, and after the theoretical background was covered in lecture. In addition, the sudden expansion exercise was conducted in a one-week span instead of the two week span for laboratory sessions involving the tank filling apparatus. The effect of the extra preparation for the sudden expansion laboratory is evident in these observations:

- More students used correct terms to discuss the sudden expansion experiment than the tank filling experiment.
- Students that conducted the tank filling laboratory exercise in the one week were sharing experiment information with other students in other weeks.
- Once the students were exposed to the theoretical background, they had a hard time understanding that difference between theoretical and measured results might be due to an inapplicability of the theoretical model. When the theoretical did not match the measured results, they assumed that the measured results were wrong and the experiment setup was faulty.

Quantitative Results

Students performing the tank-filling exercise had three different laboratory instructors: the teaching assistant assigned to the laboratory section (Quinn), the research assistant (Hsieh) for the research project, and the PI (Recktenwald). For the sudden expansion exercise, there were two different instructors: the teaching assistant assigned to the laboratory section (Quinn), and the research assistant (Hsieh). Table 3 shows that the students' scores on the laboratory exercise worksheet have a slight correlation with the instructor. The research assistant (Hsieh) graded all of the lab worksheets.

Table 3: Average scores on the laboratory exercise as a function of the instructor present when students completed the laboratory exercise. The maximum score was 30 points. T.A. is the teaching assistant assigned to the laboratory section. R.A. is the research assistant working on the project. Professor is the principle investigator.

	Number of students/Average Score		
	T.A.	R.A.	Professor
Tank-filling Experiment	9/24.6	71/27.4	23/24.6
Sudden Expansion Experiment	24/28.2	72/27.9	N.A.

Survey Results

Table 4 shows the values of R and D for the survey questions that were completed on both the pre-study survey and post-study survey; of the 73 volunteer study group 51 completed both surveys. The p-values at 95 percent confidence intervals are given for the values of D. Only the results for questions 32 and 34 are statistically significant.

The post-study survey did not make it clear that students should distinguish the conventional and inquiry-based labs in their responses. In the open-ended response section, several students wrote comments that indicated they did not understand the conceptual differences between the inquiry-based and conventional exercises. To those students, all of the lab exercises are the same, regardless of whether the grading was based on a report or an in-lab worksheet. An example of a positive (written) comment was that, "(there needs to be) less lectures, more labs". A negative comment was that, "I feel like school labs currently are usually a waste of time".

Table 4: Summary of average response for both surveys. Pre and Post columns are the average response from Likert Scale questions.

		R_{Pre}	R_{Post}	D (p-value)
31	Laboratory exercises help students learn engineering concepts	3.86	3.90	0.04 (0.596)
32	I learn a lot from laboratory exercises that are “canned”, i.e. the equipment is already configured and running properly, so all I have to do is write down the data.	2.53	3.08	0.55 (0.001)
33	I would learn more from laboratory exercise if it was not “canned”, i.e. if I was responsible for setting up the equipment and get it running myself.	3.67	3.47	-0.20 (0.104)
34	I would be willing to set up laboratory equipment myself and get it running, even if it took me twice as long as a “canned” lab to complete the assignment.	3.43	3.04	-0.39 (0.007)
35	I would be willing to set up laboratory equipment myself and get it running, but only if it took me less than 25 percent more time in the lab to complete than a “canned” experiment.	3.48	3.56	0.08 (0.701)
36	Laboratory exercises for students are not necessary if the instructor does an in-class demonstration with the same laboratory equipment.	2.77	2.67	-0.10 (0.699)
37	Laboratory exercises and homework exercises are similar because they both are ways of testing my knowledge of the course material.	3.20	2.92	-0.28 (0.172)
38	Laboratory exercises and homework exercises are similar because they both provide a way to learn important concepts about the material.	3.70	3.66	-0.04 (0.796)
39	Laboratory exercises only reinforce what is taught in lecture; they do not teach new concepts.	3.00	2.86	-0.14 (0.744)
40	Getting good data in a lab experiment is mostly due to luck because experiments rarely match theory.	2.38	2.56	0.18 (0.175)
41	Laboratory experiments are only useful for researchers.	2.10	2.10	0.00 (0.500)
42	In my future engineering job I will not need to make measurements.	1.55	1.69	0.14 (0.202)
43	In my future engineering job I will use experiments (laboratory measurements) to obtain useful engineering data.	3.78	3.77	-0.02 (0.451)
44	In my future engineering job I will use computer simulations to get data instead of making measurements in a laboratory.	3.49	3.59	0.10 (0.547)
45	Laboratory experiments (laboratory measurements) are more reliable than computer simulations for verifying the performance of an engineering design.	3.18	3.20	0.02 (0.868)

Discussion

The scores in Table 3 show that the instructor can have an effect on the success of student completion of the worksheet. This makes obvious sense, but it also suggests that using the scoring the laboratory worksheet to indicate student learning requires control for the effect of the instructor. Several students commented that each instructor had different ways of explaining the material, which affected their scores. One student wrote on their post-survey,

> "I thought the 1st lab (tank filling) was inconsistent from group to group in that some groups were coached toward answers by the researchers. Where researchers weren't present, other groups were left to find answers themselves. This affected the outcome because some of the questions were unclear and those without coaching were not given equal treatment".

The role of the instructor is especially important in an inquiry-based exercise because student learning is happening while the experiment is being performed. The worksheets have questions requiring qualitative reasoning, a form of problem-solving that many students have not mastered. Even when the instructor is careful not to provide answers to the exercises, students need guidance on how to approach the question: what is being asked? what readily available tools can help with the answer?

The tank filling laboratory exercise was conducted at the start of the quarter. The differences in student scores shown in the first row of Table 3 caused us to rethink the worksheet for the sudden expansion laboratory exercise. First an "instructor check answer" box was added to the worksheet, which made the students check their answer with the instructor before they could move on to the next part. Second, we involved the teaching assistant with the creation of the inquiry laboratory exercises. The laboratory scores for the sudden expansion experiment were much more consistent than the tank-filling experiment.

The research team did not anticipate the positive change in student attitude for Question 32 and negative change in attitude for Question 33 in Table 4. The change in responses indicates that the students in the study group viewed the conventional lab exercises more favorably at the end of the term. One explanation for this change is unfamiliarity with the inquiry-based approach. Some students were frustrated when they learned that the Bernoulli equation did not apply to the sudden expansion. One student wrote in the post-survey:

> "the 2nd experiment, sudden expansion, was poorly designed and did not reinforce concepts. It showed us where the theory does not work. However, we were still struggling to understand the basic concept. 4000% only confused us…… I want results that confirm theory, not contradict it".

This frustration may have caused a significant number of students to favor "canned" experiments because in "canned" experiments they believe that the experiment will confirm the theory.

Not all students disliked the inquiry-based experiments. There were several positive comments on the post-survey. One student wrote,

> "Testing before and after was beneficial. (This) gave the students a chance to start thinking about the concepts before the lab even began".

The other large change in student attitude is associated with their willingness to invest time into the laboratory exercises. Question 34 and Question 35 can be summarized as, "are you willing to invest a lot or a little time on an experiment that was not 'canned'?" Student responses to Question 34, would you be willing to invest a lot of time, shifted negatively during the term, i.e. students were less inclined to invest a lot more time at the end of the quarter than at the beginning. Student responses to Question 35, would you be willing to invest a little time, were essentially unchanged. The lack of interest in committing more time to academics may be influenced by student fatigue at the end of the term. We need to do follow-up interviews with students to probe the reasoning behind their answers to the survey questions.

The other questions on the survey showed little change in student responses. There are many aspects to the survey data to be explored: are the responses by men and women different? does prior work experience affect attitudes toward laboratory work? is there are difference between mechanical engineering students and civil engineering students?

Table 4 contains the first assessment data for the first deployment of the inquiry-based experiments in our fluid mechanics laboratory. We are using this experience to revise the laboratory exercises and the assessment instruments.

Conclusions

Attitudes

The students in this study had relatively small changes in attitude over the academic term. The two most prominent changes in attitude were associated with (1) the students' belief about the (negative) effectiveness of the inquiry-based exercises and (2) students' loss of interest in spending more time doing experiments that are not pre-configured and ready to run.

Instructors

The inquiry-based laboratory exercises require students to use qualitative reasoning, which is a problem-solving strategy that requires greater conceptual understanding of the material. The instructor needs to have knowledge of the subject matter and an appreciation for active learning strategies to help student answer questions requiring qualitative reasoning.

Length of the Experiment

Students are willing to put in extra time to complete an inquiry-based exercise, but only up to a point. We assume that during the pre-study survey they did not have an idea of what it meant that a laboratory exercise takes "twice as long" as a conventional exercise. After completing the laboratory exercise their awareness of the time commitment increased and their tolerance for extra effort decreased.

Lesson Learned

We have learned some things that should have been obvious to us from the start:

1. Students are unfamiliar with terms like "inquiry-based" and "pedagogy". Hence, is it not helpful to use these terms to explain the experiments or motivate student interest.
2. Students are unfamiliar with the inquiry-based approach. They can be confused and upset when confronted with assignments that do not have cookbook like instructions. There is little comfort in explaining to students that real engineering problems do not come with cookbook instructions.
3. Making the experimental apparatus "interesting" or "practically relevant" does not fully compensate for the student discomfort at being confronted with a task that they feel unprepared to successfully complete.
4. The post-lab surveys did not clearly tell the student to limit their answer to the inquiry-based experiments. This error in our instrument caused many students to report on their experience with both types of experiments in mind. The next version of our instrument will correct this flaw so that we can obtain a better measure of student attitude toward the inquiry-based and conventional laboratory exercises.

Future Work

Using the knowledge gained from implementing the inquiry-based experiment in the fluid mechanic laboratory class, we will improve the inquiry-based laboratory exercises for use subsequent academic terms. Further analysis is required on the survey data collected for Fall 2007. In particular, patterns of responses amongst subgroups in the study need to be identified. In the future we plan to conduct interviews with students to further clarify and refine the survey questions.

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Appendix A: Participant Background Survey

1. Age (optional): ______________

2. Ethnicity (optional, circle one)

   Black/African American   American Indian/Alaskan Native
   Hispanic/Latino American   White/Caucasian
   Asian/Pacific Islander   Other: ____________________

3. Gender (optional, circle one): M F

4. How many years has it been since you completed your high school degree?

5. a. Since completing high school, have you ever stopped going to school except during summer? (circle one) YES NO

   If you answer “no” to question 5a, skip to question 6

   b. How long did you work before returning to school? _______ years

   c. Approximately how many hours did you work per week? ______________

   d. Did this work involve engineering or related technical skills? YES NO

6. Do you currently have a job? (circle one) YES NO

7. If you answered “yes” to question 6, how many hours per week (on average) do you work? ______________

8. Have you already completed a college degree? If so, in what subject?

   a. No

   b. Yes, a 2 year degree in __________________ (subject, e.g. Drafting, EE Technology)

   c. Yes, a 4 year degree in __________________ (subject, e.g. Drafting, EE Technology)

9. What year are you in school?

   a. Freshman b. Sophomore c. Junior d. Senior

10. In which calendar year do you expect to graduate?

    2007 2008 2009 2010 2011 2012 Other: __________

11. Did your parents go to college? (circle one) NEITHER ONE BOTH

12 How long have you been in the upper-division engineering program at PSU? ____ years

13. Did you attend a Community College full time before coming to PSU? YES NO

    If yes, which one? ________________________

14. What is your major?

    Civil Engineering   Electrical Engineering   Mechanical Engineering
    Computer Science   Other: _______________   I don’t know

15. Approximately what is your current GPA? (circle one)

    3.5 or above   Between 3.0 and 3.5   Between 2.5 and 3.0
    Between 2.0 and 2.5   Below 2.0   I don’t know

Appendix B: Pre-Study Survey of Self Assessment of Learning Styles and Preferences

For each of the following questions, use a scale of 1 to 5 to indicate your agreement with the statement. Circle the number corresponding to the following degree of your agreement or disagreement

1. Strongly Disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly Agree

16.	I prefer laboratory measurements to lectures as a way to learn engineering course materials.	1	2	3	4	5
17.	I have a concrete learning style.	1	2	3	4	5
18.	Seeing a laboratory demonstration helps me to learn concepts better than reading about the concept in a textbook.	1	2	3	4	5
19.	Reading a textbook is more helpful for learning a new concept than running a lab experiment that demonstrates the concept.	1	2	3	4	5
20.	Attending a lecture is more helpful for learning a new concept than running a lab experiment that demonstrates the concept.	1	2	3	4	5

Self Assessment of Skills and Interests

21.	I have good practical, hands-on skills.	1	2	3	4	5
22.	I am better at building things than in doing engineering analysis with formulas.	1	2	3	4	5
23.	I am skilled at making measurements in a laboratory.	1	2	3	4	5
24.	My previous laboratory-based classes have given me the necessary training to perform engineering experiments.	1	2	3	4	5
25.	I am comfortable connecting sensors to electronic measurement equipment like multimeters, voltmeters, ammeters, power supplies.	1	2	3	4	5
26.	I am comfortable connecting sensors to data acquisition (DAQ) systems.	1	2	3	4	5
27.	I know how to use a computer controlled data acquisition (DAQ) system.	1	2	3	4	5
28.	I am interested in learning more about sensors and electronic measurement systems.	1	2	3	4	5
29.	I am interested in learning more about computer-controlled data acquisition (DAQ) systems.	1	2	3	4	5
30.	I am interested in learning more about how to write LabVIEW programs for computer-controlled data acquisition (DAQ) systems	1	2	3	4	5

Educational Value of Laboratory Exercises

31.	Laboratory exercises help students learn engineering concepts	1	2	3	4	5
32.	I learn a lot from laboratory exercises that are "canned", i.e. the equipment is already configured and running properly, so all I have to do is write down the data.	1	2	3	4	5
33.	I would learn more from laboratory exercise if it was not "canned", i.e. if I was responsible for setting up the equipment and get it running myself.	1	2	3	4	5
34.	I would be willing to set up laboratory equipment myself and get it running, even if it took me twice as long as a "canned" lab to complete the assignment.	1	2	3	4	5
35.	I would be willing to set up laboratory equipment myself and get it running, but only if it took me less than 25 percent more time in the lab to complete than a "canned" experiment.	1	2	3	4	5
36.	Laboratory exercises for students are not necessary if the instructor does an in-class demonstration with the same laboratory equipment.	1	2	3	4	5
37.	Laboratory exercises and homework exercises are similar because they both are ways of testing my knowledge of the course material.	1	2	3	4	5
38.	Laboratory exercises and homework exercises are similar because they both provide a way to learn important concepts about the material.	1	2	3	4	5
39.	Laboratory exercises only reinforce what is taught in lecture; they do not teach new concepts.	1	2	3	4	5
40.	Getting good data in a lab experiment is mostly due to luck because experiments rarely match theory.	1	2	3	4	5

Practical Value of Laboratory Exercises

41.	Laboratory experiments are only useful for researchers.	1	2	3	4	5
42.	In my future engineering job I will not need to make measurements.	1	2	3	4	5
43.	In my future engineering job I will use experiments (laboratory measurements) to obtain useful engineering data.	1	2	3	4	5
44.	In my future engineering job I will use computer simulations to get data instead of making measurements in a laboratory.	1	2	3	4	5
45.	Laboratory experiments (laboratory measurements) are more reliable than computer simulations for verifying the performance of an engineering design.	1	2	3	4	5

Your Comments

Please use the following space to add any comments about your participation in the research project.

Appendix C: Post-Study Survey

The post-study survey consisted of questions 31 through 45 from the Pre-Study Survey (Appendix B) and the following additional questions

Attitudes toward Laboratory Measurements

46.	As a result of performing experiments in this class, I am more curious about the engineering principles at work in the machines and gadgets I use everyday..	1	2	3	4	5
47.	As a result of performing experiments in this class, I am more interested in doing work in a laboratory.	1	2	3	4	5
48.	As a result of performing experiments in this class, I have a better understanding of the course material.	1	2	3	4	5
49.	As a result of performing experiments in this class, I have a better understanding of the practical use of making laboratory measurements.	1	2	3	4	5
50.	I would be interested in buying my own data acquisition (DAQ) system if it cost approximately as much as a typical engineering textbook.	1	2	3	4	5