AC 2010-1169: STUDENT ATTITUDES TOWARD INQUIRY-BASED EXERCISES IN UNDERGRADUATE LAB COURSES

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Student Attitudes toward Inquiry-Based Exercises in Undergraduate Lab Courses

Introduction

This paper reports on work in progress for a Type 1 CCLI project. The primary focus of the research project has been the development of a series of inquiry-based demonstrations and laboratory exercises appropriate for students in the third year of engineering and engineering technology programs. Students volunteered to participate in the research study by allowing the research team to track their grades and survey responses. This paper presents results from analyzing student responses to attitude surveys given before and after the use of the inquiry-based exercises.

Inquiry-Based Demonstrations and Laboratory Exercises

The exercises use common, everyday hardware such as a kitchen blender, a toaster, and a hair dryer. This equipment (1) is familiar and potentially interesting to students, (2) is inexpensive, and (3) clearly exposes important topics in the thermal and fluid sciences. The exercises are based on a guided inquiry model of pedagogy. Students follow worksheets that provide a structured active learning experience. This approach is in contrast to the conventional undergraduate laboratory experience where students follow a cookbook to collect data and then go home to analyze the data and write a report. To give the reader a more concrete idea of the laboratory exercises, we will briefly describe three of the seven pieces of equipment used in different in-class demonstrations and laboratory assignments. The intention here is to give a flavor of the student experiences that lead to the assessment results presented in the second half of the paper. Additional information on the exercises and equipment may be found on the web site eet.cecs.pdx.edu and in other publications[1-5].

Figure 1 is a schematic of a kitchen blender that is used to teach students about the role of shaft work in thermodynamic systems. The blender is partially filled with water and rigidly supported thermocouples are suspended in the water. The thermocouple output is read by a low cost, USB-based data acquisition system. When the blender apparatus is used for an in-class demonstration, the computer display is connected to the projection system in the classroom. Before the motor is turned on, students are asked to complete a worksheet of five multiple choice and short-answer questions. The questions ask students to predict the direction and magnitude of the response, and to identify the physical mechanism for any observable change in the temperature. The student responses are collected, and *only then* is the blender motor is turned on. The same apparatus is used in a two-hour laboratory exercise where students work in small groups to make measurements in response to questions on a guided-inquiry worksheet. The students use qualitative reasoning to explain how the temperature response changes with changes in the amount of water in the blender and the motor speed.

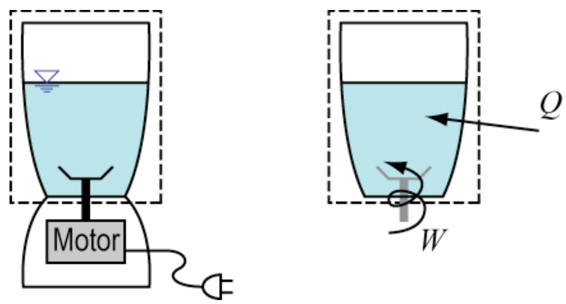

Figure 1. Application of the first law of thermodynamics to a kitchen blender.

The worksheets used in the laboratory exercises require students to (1) explicitly develop a hypothesis (make a prediction) for the behavior of the experimental system, (2) choose the operating conditions of the apparatus to test their hypothesis, (3) record data and other observations, (4) evaluate how their preconceptions matched the measured results, and (5) develop a revised model of system behavior. Because the equipment is simple and familiar to students, we believe students are more likely to reveal their misconceptions about the core concepts necessary for the equipment to function. The misconceptions are exposed when students make predictions about the system behavior and subsequently measure that behavior.

Figure 2 depicts two cylindrical tanks that are open to the atmosphere at the top. A pressure transducer is attached to the side of each tank near the base. These tanks are used in two exercises at different points during an academic term. The first exercise occurs early in the term and is aimed at developing a deep understanding of the hydrostatic equation. Because the engineering concept is rather simple, the first exercise is also used to introduce students to the guided inquiry style of laboratory exercises.

In the first exercise, students measure the output of the pressure transduer attached to the straight tank as water is added to different depths. Students plot the pressure versus depth curve (a straight line). They are then asked to sketch the pressure versus depth curve for the stepped tank. Students work in small groups, and discuss the prediction before the confirmatory measurements are made. Usually there is a disagreement within the group about whether the pressure versus depth relationship will be the same for both tanks. Students must write down a prediction about the step tank and show the prediction to the laboratory instructor before proceeding with the measurements. At the end of the lab session the worksheets are submitted for grading.

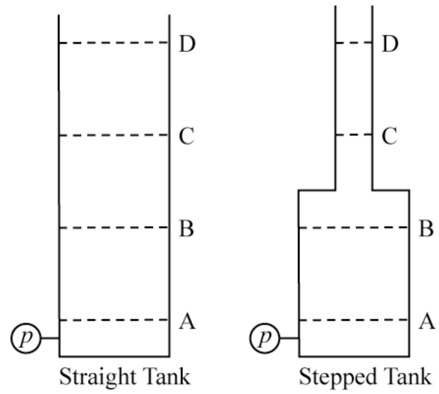

Figure 2 Two tanks used to demonstrate that pressure in a stationary liquid is independent of the shape of the vessel that holds the liquid.

Figure 3 depicts the second exercise involving transient draining of water from the two tanks. The tank-draining exercise is much more complex than the hydrostatic exercise. We found that the introduction of the hardware and the inquiry-based approach with the tank-filling exercise, help students understand the tank draining exercise. In the language of learning science, the cognitive load for the tank-draining exercise was too much unless the tank-filling exercise was used for scaffolding.

One of the key observations from the tank-draining exercise is that the distance, L, traveled by the jet of water is determined by the depth, h, of water above the hole in the side of the tank. Within the random variations caused by manufacturing tolerances and measurement errors, the $L = f(h)$ relationship is independent of tank shape and hole size. The challenge for the student is to relate the measurements of $h(t)$ and $L(t)$, which are observed directly in the lab, to the more abstract $L = f(h)$ relationship that determines the behavior of the system.

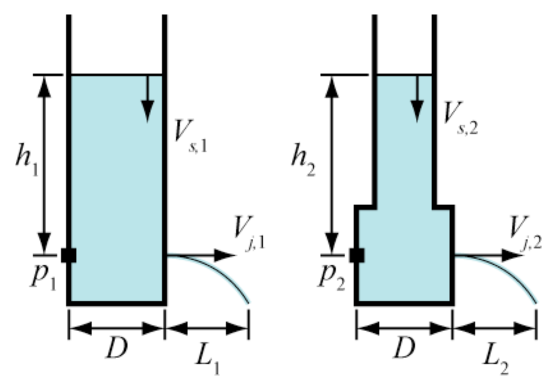

Figure 3 Transient tank-draining exercise involving the same apparatus used in the exercise on the hydrostatic principle.

Figure 4 shows the Sudden-Expansion apparatus that is used to expose and correct misconceptions about the Bernoulli equation. A blower draws air through a short section of duct that has a change in area from a smaller diameter to a larger diameter. The key part of the apparatus is the junction between the two ducts. The exercise focuses on the pressure change across the sudden expansion, and on the velocity profile downstream of the expansion. As with the other exercises, students are required to record their predictions about the system behavior on a worksheet before they make the measurements. The worksheet has several of these predict-then-confirm steps.

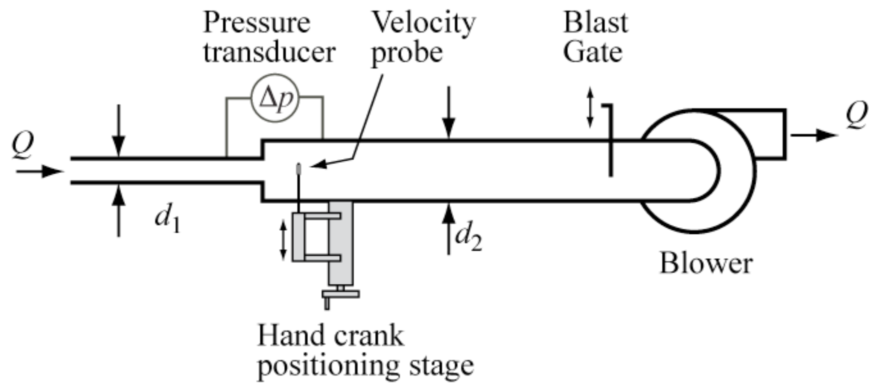

Figure 4 Sudden expansion apparatus used to expose misconceptions about the Bernoulli equation.

Before the apparatus is turned on, the students are asked to predict whether the fluid pressure increases, decreases or stays the same as the fluid moved through the sudden expansion. The students record their predictions, and then apparatus is turned on. In the absence of flow losses, the pressure must increase. For the sudden expansion device, the measured pressure change actually depends on the area ratio d_1/d_2. For $d_1/d_2 = 0.4$, the pressure increases, and for $d_1/d_2 = 0.67$ the pressure decreases.

After the first set of measurements, students are asked to develop a model that explains the pressure change. As a starting suggestion, we recommend that they compute $p_1 - p_2$ by combining the continuity equation and the Bernoulli equation. When they compare the measured $p_1 - p_2$ with the $p_1 - p_2$ from this preliminary model they find a very large discrepancy, which causes the students to confront the reality that the Bernoulli does not apply. The correct model for the flow is derived from the energy equation, which includes the head loss term.

The sudden expansion exercise has been used and refined for four years. In the early offerings the students were very frustrated and confused because the primary experience was that they could not get the simple model (based on the Bernoulli equation) to agree with their data. The point of the exercise is to show that the Bernoulli equation *does not* apply. The worksheets were refined to provide better scaffolding and reduce student frustration. In Fall 2009 the exercise was more successful in that students seemed better able to follow the reasoning in the worksheets and they certainly complained less about the experience.

Assessment

Students on the two campuses did not perform identical exercises during the time intervals over which attitudes and attitude changes were measured. At Penn State Behrend, students performed inquiry-based exercises involving the blender, hair dryer and tank filling. At Portland State, students performed inquiry-based exercises involving the blender, tank-filling, tank draining, and sudden expansion. Thus, in addition to the inevitable differences in instructors, academic programs, and general campus environments, the pedagogical treatments differed. The potential influence of these differing experiences should be kept in mind when considering measured attitude changes on the two campuses.

At the start of the quarter in Fall 2008, two surveys were administered to the students in the study group, which consisted of students who volunteered to participate in the research project. Volunteering meant consent to complete background and attitude surveys, and to allow the research team to correlate these surveys with course grades. One survey collected demographic data, and the other aimed to discover preferred modes of learning, students' self-assessed laboratory skills and interest, and their attitude toward laboratory work. At the end of the quarter, a second attitude survey was given to the study group. The post-course survey included 15 questions that were on the pre-course attitude survey, and an additional 22 questions about the students' experience in the course and with the laboratory exercises. The data discussed in the rest of this paper is for the 177 students who completed all instruments in Fall 2008. Some preliminary data from Fall 2009 is also presented. The attitude survey responses use a 5-point Likert scale, where 1 means strongly disagree, 3 is neutral, and 5 means strongly agree.

In an earlier paper we discussed the *change* in survey responses for the questions in common to both the pre and post-course surveys. That analysis showed that student attitude toward laboratory exercises was less favorable at the end than at the beginning of the course[6]. As will be shown later, the survey measurements of the pre/post change in attitude during the term did not have high internal reliability. In contrast, the internal reliability was good for questions appearing only on the post-course survey. In this paper we report on more detailed analysis of just the post-course survey results.

Student Populations

The guided-inquiry exercises were tested on two campuses that are different in several ways. Portland State University (PSU) is located in an urban center and has a historic mission of access to students who are place-bound by family and/or work commitments. Many of the students live off-campus and many have part-time or even full-time work in addition to their classes. Penn State – Behrend (PSB) has a more traditional student population, with students who primarily are attending college immediately after graduating from high school. PSU has a total enrollment of approximately 21,000, whereas PSB has a total enrollment of approximately 4800.

Some of the categorical differences between the campuses are summarized in Table 1. The sizes of the two study groups (students who volunteered to participate) are approximately equal: 79 at PSU versus 88 at PSB. One of the primary differences is that the students in the study group from PSU are older than the students from the study group from PSB. The age distributions for the campuses are shown in Figure 5. The study group from PSU is slightly more diverse (more women and more non-Caucasians) than study group from PSB.

Consistent with the older population distribution, the students in the study group from PSU had more prior two-year and four year degrees than the students from PSB. The students from PSU are predominantly enrolled in either Civil Engineering or Mechanical Engineering programs. The students from PSB are enrolled mostly in Electrical Engineering Technology, Mechanical Engineering Technology or Plastics Engineering programs.

Table 1 Summary of characteristic distinguishing the two populations of students in the study group.

Characteristic	Portland State University	Penn State – Behrend
Participants	79	88
Ages of students	Mean = 25.8 Median = 24	Mean = 21.2 Median = 21
Gender composition	80% male, 20% female	89% male, 11% female
Ethnicity	84% Caucasian	94% Caucasian
Prior degrees	60% None 26% two-year 14% four-year	91% None 9% two-year
Major	58% Civil Engineering 36% Mechanical Engineering 6% Other	15% Electrical Engineering Technology 3% Mechanical Engineering 39% Mechanical Engineering Technology 32% Plastics Engineering 2% Other

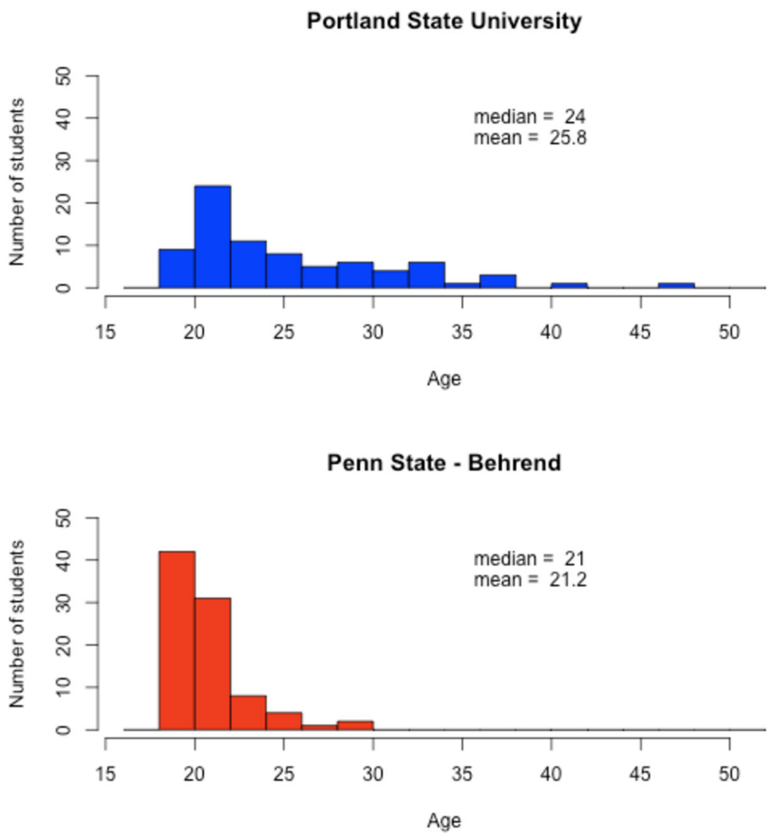

Figure 5 Distribution of ages for study participants on the two campuses.

Students can also be classified by how much they work to earn money while enrolled in classes. Table 2 summarizes the survey responses about whether students have jobs and if so, how many hours per week. To simplify the display and analysis, survey responses were binned into categories of 8 hours. Thus the hours-per-week descriptor was transformed to (approximately) the number of days-per-week that a student works. In Table 2, “One day” refers to either the number or the percent of students who work more than zero and less than or equal to 8 hours. “Two days” refers to students who work more than 8 and less than or equal to 16 hours per week. The data in Table 2 is presented as counts of students in each category of days-worked-per-week. The data is also presented as the percentage of students in each category. Across each row, the percentages add to 100, to within round-off.

Students in the study groups from both campuses report a significant commitment to work outside of classes. The differences between the campuses in the amount and type of non-academic work are not as pronounced as the differences in age distribution between the two campuses. For example, a higher percentage of students on the PSB campus work than the student group on the PSU campus (53 percent versus 37 percent). However, the students at PSU who have jobs tend to work more hours per week than the students from PSB who have jobs. Additional statistical analysis (of the type reported later in this paper) reveals no significant relationship between student attitude and the amount of work outside of classes. The sample sizes for the subgroups may not be large enough (low statistical power) to detect the differences. Also remember that these descriptive statistics only apply to the study group, i.e. those who volunteered to participate in the research.

Table 2. Work commitment outside of classes for students in the study group. Refer to the text for a description of the categories for the amount of work. PSU = Portland State University. PSB = Penn State – Behrend

Number of Students

Campus	None	One day	Two days	Three days	Four or more days
PSU	30	8	11	23	9
PSB	47	8	15	15	4
Combined	77	16	26	38	13

Percentage of Respective Group

Campus	None	One day	Two days	Three days	Four or more days
PSU	37%	10%	14%	28%	11%
PSB	53%	9%	17%	17%	4%
Combined	45%	9%	15%	22%	8%

Instruments and their reliability

The Cronbach alpha statistic is an indicator of the internal reliability of surveys that measure student attitude toward laboratory work and the EET exercises[7]. The confidence interval on alpha is computed with the formula suggested by Iacobucci and Duhachek[8]. Table 3 lists the overall Cronbach alpha for the pre-course and post-course surveys, and the overall alpha for the change in responses (from pre to post) to the fifteen questions common to the pre-course and post-course survey. The second column (labeled "Combined") shows the alpha values for the surveys from both PSU and PSB. The third and fourth columns are the alpha values when the survey responses for each school are analyzed separately.

Table 3 Cronbach alpha for pre/post surveys conducted in Fall 2008. Values in brackets, e.g. [0.58,0.73] are the 95 percent confidence interval.

Instrument or measure	Combined	PSU	PSB
Pre-course survey (30 questions)	0.65 [0.58, 0.73]	0.56 [0.42, 0.69]	0.73 [0.65, 0.81]
Post-course survey (29 questions)	0.84 [0.81, 0.87]	0.84 [0.80, 0.89]	0.78 [0.71, 0.85]
Change (15 questions)	0.41 [0.29, 0.54]	0.35 [0.14, 0.56]	0.49 [0.33, 0.64]

The data in Table 3 show that the pre-course survey is less reliable than the post-course survey. The alpha = 0.65 for the combined pre-course survey responses is close to, but below the value of alpha=0.70 commonly used as a threshold for internal reliability. Note also that the upper end of the 95 percent confidence interval is only 0.73.

When the survey responses for the two schools are separated, the internal reliability of the PSU data is significantly lower on the pre-course survey than the PSB responses on the same survey: alpha = 0.56 versus alpha = 0.73. Furthermore, the 95 percent confidence intervals for those scores are only barely overlapping. We do not have a working hypothesis for the difference in reliability for the same survey administered on the two campuses. The reliability analysis indicates that we should be cautious about drawing conclusions from any data that uses the pre-course survey data from PSU.

The internal reliability of the post-course survey responses is uniformly good. The combined and school-based responses all have alpha > 0.7 and the lower bounds for the confidence interval are also alpha > 0.7.

The data for attitude change in the last row of Table 3 show that one should not make too much of numerical scores for the change in attitude. Not even the upper limit of the confidence intervals exceeded the alpha = 0.7 threshold for and of the change in attitude measures. The rest of this paper focuses on the post-course survey results.

Post-course Attitudes Survey

There is a difference in the responses to the post-course survey for the study group participants on the two campuses. The difference is apparent when comparing the mean of the responses to each of the 14 questions on the post course survey. Consider responses to Statement 46: *The inquiry-based laboratory exercises have increased my curiosity about the application of engineering principles to the machines and gadgets I use every day*. Figure 6 shows three histograms of the Likert scale responses to Statement 46. The attitude survey responses are indicated with a 5 point Likert scale, where 1 means strongly disagree, 3 is neutral, and 5 means strongly agree. Students from PSB (mean 3.95) tend to agree more strongly than students from PSU (mean 3.48).

The sets of inquiry-based exercises were not the same on the two campuses, and that might explain the differences in responses to Statement 46. In particular, the mix of exercises involving "everyday gadgets" was different. Penn State Behrend students performed exercises with the blender and hair dryer, whereas the Portland State students performed exercises with the blender. Therefore, the attitude response measured in the post-course survey cannot, with certainty, be attributed to the intrinsic properties of the EET exercises because the assignment of treatment within the overall study group was not random, but instead was correlated with the campus.

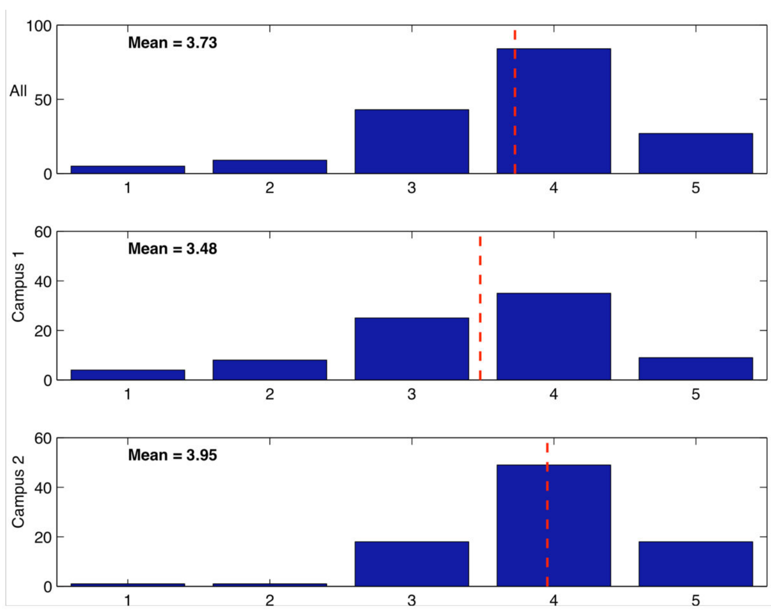

Figure 6 Distribution of responses to statement 46. Campus 1 is Portland State University. Campus 2 is Penn State Behrend.

Table 4. Survey statements and mean responses for students during Fall 2008 and Fall 2009. The Fall 2009 data is only for PSU. The research team is still collecting data for analysis on PSB.

	Survey Statement	2008	2009*
46.	The inquiry-based laboratory exercises have increased my curiosity about the application of engineering principles to the machines and gadgets I use every day.	3.43	3.77
47.	The inquiry-based laboratory exercises have increased my interest in laboratory work.	3.09	3.52
48.	The inquiry-based laboratory exercises have increased my understanding of course material.	3.59	3.71
49.	The inquiry-based laboratory exercises helped me understand the practical need for laboratory measurements.	3.54	3.88
50.	I would like to have a data acquisition system to use with my personal computer.	3.39	3.46
51.	The EET experiments and demonstrations have improved my ability to apply my engineering knowledge to practical problems.	3.34	3.74
52.	The EET laboratory exercises have increased my ability to reason about the First Law of Thermodynamics.	3.23	3.39
53.	The EET laboratory exercises have increased my ability to reason about the Bernoulli equation.	3.52	3.98
54.	The EET laboratory exercises increased my confidence that I can correctly apply fundamental equations like the First Law of Thermodynamics and the Bernoulli equation.	3.36	3.83
55.	I decided to participate in the EET project because an in-class demonstration of an EET experiment made me curious.	2.59	2.69
56.	I decided to participate in the EET project because I am willing to try anything that might help me get a better grade.	3.23	3.01
57.	I would recommend the EET exercises to a friend.	3.44	3.68
58.	I would recommend the EET exercises to a friend who wants to learn more about core concepts in fluid mechanics, thermodynamics, or heat transfer.	3.51	3.86
59.	I would recommend the EET exercises to a friend who is interested in improving his/her grade.	3.27	3.18

*Data for 2009 only contains responses from PSU, and should be considered tentative.

Table 4 lists the questions from the post-course survey, and the responses from students in Fall 2008. The last column of Table 4 gives preliminary data from Fall 2009, but only for students at PSU. It is important to note that the cohort from Fall 2009 is different from the cohort from Fall 2008.

The data in Figure 6 suggest the possible existence of additional differences in attitude for the two study groups. To explore this data further, the difference in mean responses is assessed with a two-tailed t test of the mean response to each question in the post-course survey. The null and alternative hypotheses for the t tests are:

H_0: The mean response of student volunteers at PSU is the same as the mean response of student volunteers at PSB

H_1: The mean response of student volunteers at PSU is different from the mean response of student volunteers on PSB.

Computations for the hypothesis tests are carried out with the R programming system for statistical analysis[9]. For the responses to Question 46, $t = -3.83$. The negative sign means that the response of students in the PSU study group is less positive than the response of students in the PSB study group. The p value for this test is 0.00019, meaning that a magnitude of $|t|$ as large as 3.83 would occur in a random sample 19 out of 100,000 times or approximately 2 in 10,000. Therefore, the observed t value is unlikely to occur by chance. We reject the Null Hypothesis and conclude that the observed difference is statistically significant.

Repeating the statistical analysis described in the preceding two paragraphs, we obtain the results in Table 5. Two important trends are evident in this table. First, for almost all questions the t statistic is negative, i.e. the response of students in the PSU study group is more negative that the response of students in the PSB study group. The second observation is that the p values are all very small, meaning that there is very strong evidence that the difference in attitudes for the two campuses cannot be explained by random responses by the participants.

Questions 47, 48 and 51 have large negative t values, i.e. they show a strong difference in attitude between students on the two campuses. These questions relate to the students' interest in laboratory work, and their belief that the EET exercises contributed to improved learning. One interpretation of this result is that the EET exercises are somehow better suited to the PSB students. Another interpretation is that the student experience at the two campuses was different in a way that contributed to a difference in their attitude toward the EET exercises. We suspect that both effects are present, but our study design does not allow us to draw strong conclusions. In the following discussion we describe some of the differences in student experiences on the two campuses. This is not an attempt to discount the potential significance of a differential benefit of the EET exercises on the two campuses. Rather, it is to caution against reading too much into the results of the 2008 post-course survey results.

Table 5 Result of two-tailed t test on H_0: *the mean response of students to the post-course survey is the same for students on the two campuses*. The ••• symbol in the last column indicates $p < 0.01$

#	t statistic	p-value	
46	-3.83	0.00019	•••
47	-4.89	2.7×10^{-6}	•••
48	-4.24	3.9×10^{-5}	•••
49	-3.28	0.0013	•••
50	-0.84	0.40	
51	-4.20	4.6×10^{-5}	•••
52	-7.14	3.7×10^{-11}	•••
53	0.57	0.57	
54	-3.12	0.0022	•••
55	-3.90	0.00015	•••
56	-4.39	2.3×10^{-5}	•••
57	-3.63	0.00041	•••
58	-4.63	8.6×10^{-6}	•••
59	-5.62	1.4×10^{-7}	•••

Question 52 has the highest absolute value of the t statistic. Question 52 asks students about the utility of the EET exercises in learning about the First Law of Thermodynamics. The blender, and hair dryer are the two exercises that deal most directly with the First Law. At PSB the blender and hair dryer exercises were required. At PSU, the blender and hair dryer equipment were used as demonstrations during lecture and were available for laboratory sessions with voluntary participation. Only a small fraction of the study group at PSU participated in the voluntary exercises. Therefore, a plausible explanation for the difference in attitude on Question 52 is simply the difference in treatment to the study groups.

Question 59 has the second highest absolute value of the t statistic for the tests summarized in Table 5. This question asks students whether the EET exercises might contribute to improved grades. Student frustration over the tank draining and sudden expansion exercises at PSU are a likely contributor to the difference in attitude on the Penn State and Portland State campuses. In Fall 2008, the tank draining and sudden expansion exercises were only performed at Portland State. The lab periods allotted to those exercises were too short. One of the consistent themes from the free response part of the survey was that students felt rushed. In response to this feedback the lab sections were reorganized in Fall 2009 at PSU to allow more time for the tank draining and sudden expansion exercises.

Other issues at Portland State were a lack of direct control over course instruction, and a miscommunication over the grading of the lab exercises. At Portland State, Co-PI Recktenwald and his research assistants supported the laboratory sections of the courses taught by other instructors. Further complicating the situation, one of the two lecturers for the course changed the grading status of the laboratory exercises during the term. At the start of the term, the research team, in consultation with the instructors, told the students that the inquiry-based exercises would count toward their course grade. Midway through the term one of the instructors decided that those exercises would not count. Therefore, it is plausible that the logistical and administrative problems contributed to PSU students' belief that the EET exercises would not contribute to improved grades.

The last column in Table 4 shows preliminary data for the post-course survey from students at Portland State only. Insufficient numbers of students completed the second (end-of-term) survey at Penn State Behrend. The responses in 2009 to all questions except number 56 and number 59 are more positive than the combined responses from both campuses in 2008. In Fall 2009, much greater care was taken to coordinate with the course instructors, and to provide better preparation for students before they arrived for their laboratory session. We believe that this explains the improvement in attitude scores from 2008 to 2009 as indicated in the last two columns of Table 4. More conclusive statements about the significance of the difference between the 2008 and 2009 data will require more analysis.

Discussion

The instructor and learning environment can have a large influence on the learning outcomes and on student attitudes. The data in Table 5 suggest that the students Penn State—Behrend (PSB) either benefited more from their exposure to the EET exercises, and/or they had a more positive learning experience than the students on Portland State (PSU). The change in student responses from Fall 2008 to Fall 2009 suggest that the student experience in the laboratory may be more important that the pedagogical intervention of the inquiry-based exercises.

This paper is a progress report on the EET project. The primary goal of the research team has been the development of the laboratory equipment and the guided-inquiry curriculum that uses the equipment. Feedback from the assessment instruments has been used to improve the design of the guided-inquiry exercises. It is clear that better controls over the experimental conditions will be required before the results of attitude surveys can be applied to a broader audience. It is also clear that innovative curriculum cannot compensate for poor execution in the delivery of instruction.

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