AC 2007-781: ASSESSING THE IMPACT OF INNOVATIVE ME COURSES: CREATING AND VALIDATING TOOLS

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Dr. George is an Assistant Professor in mechanical engineering at the University of St. Thomas. She teaches the core course in thermodynamics and has received outstanding student evaluations on her engaging teaching style. She maintains a strong interest in technology literacy and educating the general public. Professor George has prepared several innovative courses. She has taught a course specifically about fuel cells that mixed senior engineering students with students from other disciplines and adult learners (non-engineers). Professor George has also spearheaded several international service-learning projects in Haiti and Mali. These innovative projects included students from the department of Modern and Classical Languages, the communication studies department and the engineering program for an interdisciplinary year-long effort.

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Professor Yvonne Ng, MSME, is an Instructor of Computer Science in the Mathematical Science department at the College of Saint Catherine. An automation design engineer, she brings this practical industrial experience to her students. Students have evaluated her as enthusiastic as well as demanding in all of her courses, and she was awarded the Faculty Teaching and Advising Award ("Teacher of the Year") for 2003-04. Both her computer science and engineering courses are innovative in their methods to make these traditionally male-oriented subjects accessible, useful, and achievable for the female population at CSC. Professor Ng has always been interested in engineering education and women in engineering. In 1993, she co-edited a book on Princeton women engineers' reflections about their education and their identity as engineers. She served as the faculty co-leader for the college's Center of Excellence for Women, Science and Technology from 2002-2005.

Assessing the Impact of Innovative ME Courses: Creating and Validating Tools

Abstract

The goal of this research was to devise three measurement tools to assess the effectiveness of laboratory innovations for undergraduate engineering courses. The first tool was devised to measure attitudes and impressions about module content and delivery as well as attitudes toward engineering in general. We included a novel method for evaluating attitude by developing an adjective checklist that varied by gender (adjectives were masculine or feminine, negative, positive, or neutral). This was intended to gauge whether mechanical engineering, usually perceived to be masculine in nature, would gain a more gender-balanced image through innovative laboratory experiences. The second tool utilized conceptual questions (requiring no formal calculations) in a pretest-posttest format to determine whether students learned the laws of thermodynamics. The third tool took the form of a behavioral rubric designed to assess whether and how well students demonstrate knowledge of thermodynamics in subsequent settings such as internships and advanced mechanical engineering courses. Content validation of all measurement tools was conducted using engineering experts. Methodological strategies and challenges will be discussed.

Assessment Needs

Recently, a new course, *Engineering in Your World (EYW)*[1], which fulfills the general education requirement for a science lab course, was developed at the College of Saint Catherine, and the course content for *Thermodynamics*[2] at the University of St. Thomas was revised. The revisions were in the spirit of the liberal arts and included hands-on and group activities[3], a focus on minimizing negative environmental impact[4], consideration of social consequences[5], and to challenge student stereotypes of a typical engineer[6]. In order to assess these innovations we decided to measure effectiveness on multiple levels: attitudinal, learning, and behavior change[7]. Attitudes toward a course are typically measured by student evaluations at the end of a course. Often these measures are standard across disciplines and, thus, are unable to capture information that speaks to specific course goals. Learning is typically measured by quizzes and test after the information is covered in class. Behavior change as a result of the course is usually assumed rather than measured.

We began the study described in this paper in 2004 by completing literature reviews in three fields of research (psychology, education, and engineering) before concluding that we needed to develop our own tools if we wanted to attempt to truly identify *change*. Essentially there were no standard, validated tools that met our needs. Thus, we set out to create and validate our own.

Effectiveness measures were developed on three levels: attitude, learning, and behavior:

- Pre- and post-course attitude surveys for students
- Pre- and post-course learning tests (calculation based and conceptual versions)
- Behavior rubric used by supervisors and faculty

Assessing Attitudes

Attitudinal criteria measure student impressions about course content and delivery. This level of measurement assesses students' comfort level, whether they understood the material, and whether they plan to use the material in the future. Feedback from this type of measurement can be used to modify course content or presentation if necessary. More importantly for our project, this information was critical for determining whether students' stereotypes of engineering existed, changed, and if so, how they changed. To observe attitudinal change, one can compare pre- and post- responses among students completing each course. Also, one can contrast participants' responses to a similar comparison group, in our case, students taking other laboratory science courses (such as biology and physics).

We initially scanned the literature (psychology, education, and engineering) and the internet for attitudinal surveys and questions relevant to engineering knowledge, skills, and abilities. We were not able to find materials both relevant to the specific course content and that have shown sufficient reliability and validity. Thus, we developed our own attitudinal measures (see Appendix A). We began the survey with an open-ended question asking for adjectives that would describe an engineer for the purpose of obtaining attitudes free of any specific prompting. Then, students were asked how familiar/comfortable they were with aspects of the course delineated in the syllabus (for Thermodynamics) or based on guidelines from the International Technological Education Association (for *EYW*). An innovative feature of this tool is an adjective checklist that we generated to include masculine, feminine, and gender neutral terms to describe careers. Students were asked to select adjectives that they think describe engineering. Our hypothesis was that more feminine adjectives will be generated and selected after experiencing the innovative, team-oriented labs.

Development of Gender-stereotyped Adjective List

In order to measure students' perceptions of Engineering as masculine, feminine, or gender neutral, as well as positive, negative, or neutral, we made a list of adjectives which students use to describe engineering before and after they take each course.

The first step in constructing an appropriate list of adjectives was to search for fitting terms in journal articles. Key words such as "gender stereotypes" were used to conduct these searches. Another means of finding appropriate adjectives was through the university's Career Center. There were many books about how to achieve a quality education and what skills employers were looking for in employees. All applicable adjectives were written down to form a large list.

Once articles with relevant terms were scoured, the adjectives were combined into a master list. From the master, we took out words that were not relevant to careers, edited some terms to make them more understandable, and added a few relevant terms we thought of ourselves. At this point, the master list contained about 250 adjectives.

The list was then given to the Psychology Research Network. The Network was made up of faculty and junior and senior Psychology majors. They evaluated each term as masculine, feminine, or gender neutral, as well as positive, negative, or neutral. They also crossed out terms which were unfamiliar to them.

Next, the lists were analyzed and adjectives were classified according to majority judgment. There were nine people present at the Psychology Research Network the day of the evaluation, so when analyzing the data, we focused on only the terms that had a five or more person consensus. Any terms that were considered neutral by majority, words that three or more people marked as unfamiliar, and words with less than a five person consensus in either direction were discarded. From there, four master lists were made; positive female terms, positive male terms, negative female terms, and negative male terms. They were listed in order of majority agreement, nine being the highest, and five being the lowest. Interestingly, the positive female terms were most often agreed upon. From there, our research team decided on how many terms off the master lists should be used, focusing on the terms highest on the lists for a total of 34 adjectives (see Table 1).

Table 1: Final List of Adjectives Used in Checklist

Masculine	**Feminine**	**Neutral**
negative	**negative**	**negative**
authoritative	anxious	anti-social
dangerous	dependent	isolated
dominant	submissive	stressful
macho	weak	tedious
positive	**positive**	**positive**
adventurous	caring	ambitious
enterprising	cooperative	assertive
strategic	independent	committed
strong	intuitive	credible
		determined
		diligent
		disciplined
		ethical
		initiative
		innovative
		intellectual
		inventive
		professional
		successful

Assessing Learning

One critical step is to determine whether students have learned course material. *Learning criteria* measure the cognitive impact of a course. Students respond to questions about content before and after course completion. If courses are effective, post-course knowledge, skills, and abilities should increase from the pre-course baseline. Additionally, participant performance can be compared to that of students who have taken the comparable core courses such as physics, determining similarities and differences in understanding key engineering concepts (e.g., the first and second laws of thermodynamics).

Development of Learning Measures

For the *EYW* course, the Engineering GRE was reviewed to create the learning test. The first criterion was that questions needed to be conceptual in nature, so factual and computational questions were eliminated. The remaining questions (n = 80) were placed on index cards for sorting.

Three practicing engineers (either university faculty or practitioners) were utilized as experts to generate relevant test questions. They provided data in person via individual interviews. First, practitioners were shown syllabi for each class. Then the experts were asked to sort the stack of potential questions. During sorting, each question was evaluated first for its relevance based on content of course syllabi. Items were kept if experts unanimously agreed that they were relevant. Next, questions were sorted according to topic based again on unanimous agreement. Third, questions were sorted within topic in terms of difficulty (easy, moderate, and difficult). This three-step method resulted in a final version consisting of five questions (load, pulleys, rotation, compressors, etc.).

For the Thermodynamics course, several commonly available teaching and evaluation resources were scoured for conceptual questions. However, most questions required calculations such that students would be unlikely to complete the questions during a pretest even if they intuitively understood the underlying concepts. Thus, we utilized a set of conceptual questions (See Appendix B) and compared students' scores to the course professor's final exam to determine construct validity (students doing better on professor's final will also do better on the conceptual test).

Assessing Behavior

Behavior criteria measure whether students can use acquired knowledge, skills, and abilities outside of the classroom setting. Ordinarily, one obtains this type of information from people in a supervisory role (managers in an internship, professors in an advanced course). Since there is no systematic subsequent course or activity to use for follow up, we attempted to track students individually to determine whether and how they use learned knowledge, skills, and abilities in other situations (e.g., courses, internships, decision-making).

Development of Behavior Rubric

We designed a behavior rubric based on ABET outcome criteria (Apply knowledge of Math, Science and Engineering; Design and Conduct Experiments; Design a System, Component or Process; Function on Multidisciplinary Teams; Identify, Formulate and Solve Engineering Problems; Professional and Ethical Responsibility; Communicate Effectively; Understand Global and Societal Impact of Engineering; Lifelong Learning; Knowledge of Contemporary Issues; and Use Techniques, Skills and Modern Engineering Tools). We crossed these criteria with evaluation categories (poor, competent, exceptional). For self-assessment, several categories were added to evaluate the extent that *Thermodynamics* and *EYW* had influenced their abilities, and to provide examples of how they used these skills in their internship, advanced courses, etc.

Four engineers (either university faculty or practitioners) were utilized as experts. Individually they were asked to develop examples of behaviors that would represent poor, competent, and exceptional levels of each ABET criterion (See Appendix C).

Results for Attitude Assessment

Familiarity. Checklists of course concepts were analyzed to determine whether students believed they increased their familiarity with mechanical engineering.

For Thermodynamics we generated a list of topics that students were to learn during the course of the semester. This list included: turbines, nozzles, compressors, pumps, vapor systems, combustion, refrigeration, heat pumps, ideal gasses, math concepts of integrals and differentials, physics concept of work, physics concept of energy, physics concept of heat, physics concept of closed systems, physics concept of open systems, physics concept of cycles, physics concept of enthalpy, physics concept of entropy, finding and using thermo-physical data, and contemporary issues governing energy conversion.

A comparison of pre- and post-course familiarity with these topics (using single-sample t-tests of difference scores) demonstrates significant increase in self-reported familiarity for all topics except for math concepts of integrals and differentials, the physics concept of work, and the physics concept of energy. Table 2 presents the t-test results and Figure 1 presents the pretest and posttest means.

Table 2: T-Test Results for Thermodynamic Concept Familiarity

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
TURBINES	11.250	22	0.000	2.2609	1.8441	2.6776
NOZZLES	10.079	22	0.000	2.1304	1.6921	2.5688
COMPRESSORS	9.211	22	0.000	1.9130	1.4823	2.3438
PUMPS	9.529	22	0.000	1.5652	1.2246	1.9059
VAPOR SYSTEMS	7.895	22	0.000	2.2174	1.6349	2.7998
COMBUSTION	4.041	22	0.001	0.9130	0.4445	1.3816
REFRIGERATION	8.200	22	0.000	1.7826	1.3318	2.2335
HEAT PUMPS	16.045	22	0.000	2.4348	2.1201	2.7495
IDEAL GAS	5.380	22	0.000	1.2174	0.7481	1.6867
MATH CONCEPTS OF INTEGRALS & DIFFERENTIALS	0.419	22	0.680	0.0870	-0.3438	0.5177
PHYSICS CONCEPT OF WORK	1.226	22	0.233	0.2174	-0.1504	0.5852
PHYSICS CONCEPT OF ENERGY	1.298	22	0.208	0.2609	-0.1559	0.6776
PHYSICS CONCEPTS OF HEAT	3.678	22	0.001	0.7391	0.3224	1.1559
PHYSICS CONCEPTS OF CLOSED SYSTEMS	6.292	22	0.000	1.3478	0.9036	1.7921
PHYSICS CONCEPTS OF OPEN SYSTEMS	6.098	22	0.000	1.4783	0.9755	1.9810
CYCLES	6.287	21	0.000	1.8636	1.2472	2.4801
ENTHALPY	6.696	22	0.000	1.5652	1.0804	2.0500
ENTROPY	5.737	22	0.000	1.4348	0.9161	1.9535
USING THERMO-PHYSICAL DATA	6.512	22	0.000	1.7826	1.2149	2.3503
CONTEMPORARY ISSUES GOVERNING ENERGY CONVERSION	5.298	22	0.000	1.5217	0.9261	2.1174

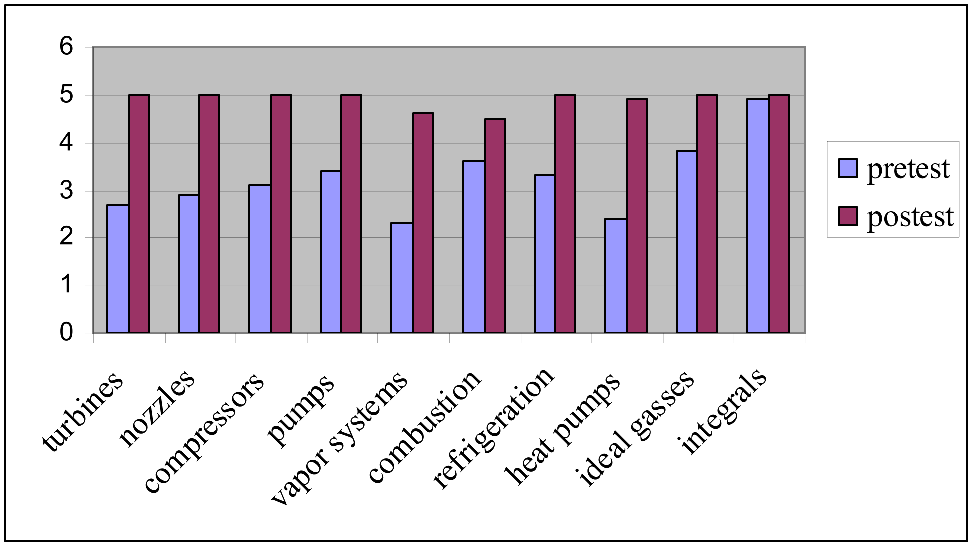

Figure 1. Pretest-Posttest Comparison of Concept Familiarity

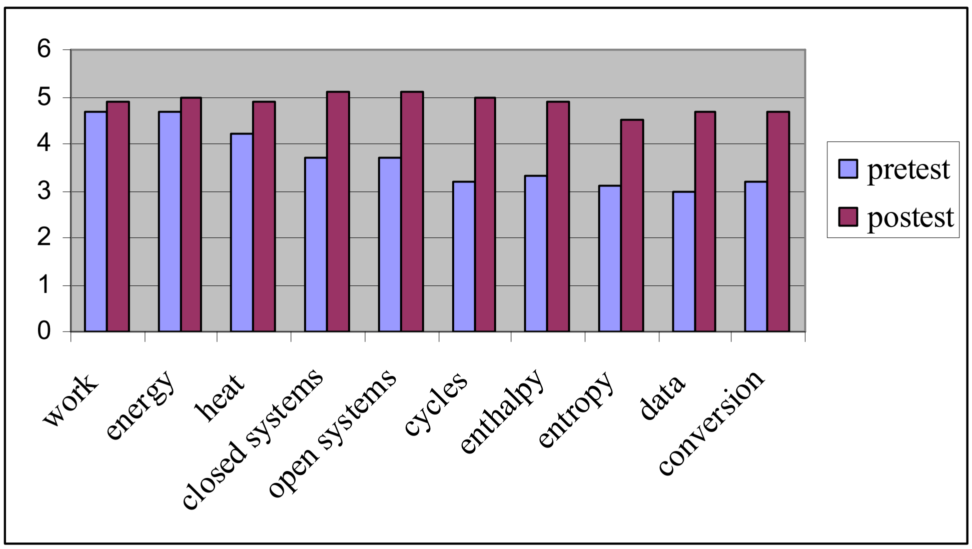

Figure 1. Continued

For *EYW* we used the standard guidelines from the International Education Association (http://www.iteawww.org/TAA/Listing.htm) to evaluate the level of familiarity students have with the materials presented during the *EYW* course. These topics included free hand drawing, technical drawing, physics concepts (force, work, energy and power), hydraulics, pneumatics, electronics, structures (statics, compression, tension, and bending), mechanisms (springs, gears, and pulleys), constructing devices and structures from everyday materials, and material types and characteristics.

A Multivariate Analysis of Variance comparing pre- and post- course familiarity among *EYW* students and their counterparts taking comparable biology and physics labs displayed significant difference by group and time. Specifically, *EYW* students consistently believed they were more familiar with topics after the course than at the beginning of the course. In comparison, there was no change from pre-course to post-course beliefs for biology students. Physics students displayed a comparable change on four of the ten topics (physics concepts, hydraulics, electronics, and mechanisms). In all cases, *EYW* students ended the course with the highest estimates of familiarity. Table 3 presents the MANOVA F-test results and Figure 2 presents the mean change in familiarity.

Table 3: Multivariate Analysis of Variance of Concept Familiarity by Group (EYW, Physics and Biology), Version (Pretest-Posttest) and the Group by Version (Group*Version) Interaction.

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
GROUP	freehand drawing	10.390	2	5.195	4.308	0.016
	technical drawing	24.380	2	12.190	11.588	0.000
	physics concepts of force, work, energy, power	43.884	2	21.942	29.691	0.000
	hydraulics	16.185	2	8.092	9.107	0.000
	pneumatics	37.262	2	18.631	19.408	0.000
	electronics	5.215	2	2.608	3.592	0.031
	structures (statics, compression, tension, bending)	59.628	2	29.814	31.586	0.000
	mechanisms (springs, gears, pulleys)	20.605	2	10.303	13.407	0.000
	devices and structures from everyday materials	21.901	2	10.951	11.277	0.000
	material types and characteristics	31.542	2	15.771	18.124	0.000
VERSION	freehand drawing	12.724	1	12.724	10.551	0.002
	technical drawing	20.322	1	20.322	19.318	0.000
	physics concepts of force, work, energy, power	13.360	1	13.360	18.079	0.000
	hydraulics	26.925	1	26.925	30.301	0.000
	pneumatics	35.796	1	35.796	37.290	0.000
	electronics	9.623	1	9.623	13.254	0.000

	structures (statics, compression, tension, bending)	8.052	1	8.052	8.531	0.004
	mechanisms (springs, gears, pulleys)	11.593	1	11.593	15.087	0.000
	devices and structures from everyday materials	8.513	1	8.513	8.767	0.004
	material types and characteristics	8.229	1	8.229	9.457	0.003
GROUP * VERSION	freehand drawing	4.723	2	2.362	1.958	0.146
	technical drawing	9.985	2	4.993	4.746	0.011
	physics concepts of force, work, energy, power	11.328	2	5.664	7.664	0.001
	hydraulics	31.164	2	15.582	17.536	0.000
	pneumatics	36.793	2	18.397	19.164	0.000
	electronics	9.612	2	4.806	6.620	0.002
	structures (statics, compression, tension, bending)	3.451	2	1.725	1.828	0.166
	mechanisms (springs, gears, pulleys)	4.021	2	2.011	2.616	0.078
	devices and structures from everyday materials	12.873	2	6.437	6.628	0.002
	material types and characteristics	5.425	2	2.713	3.117	0.048

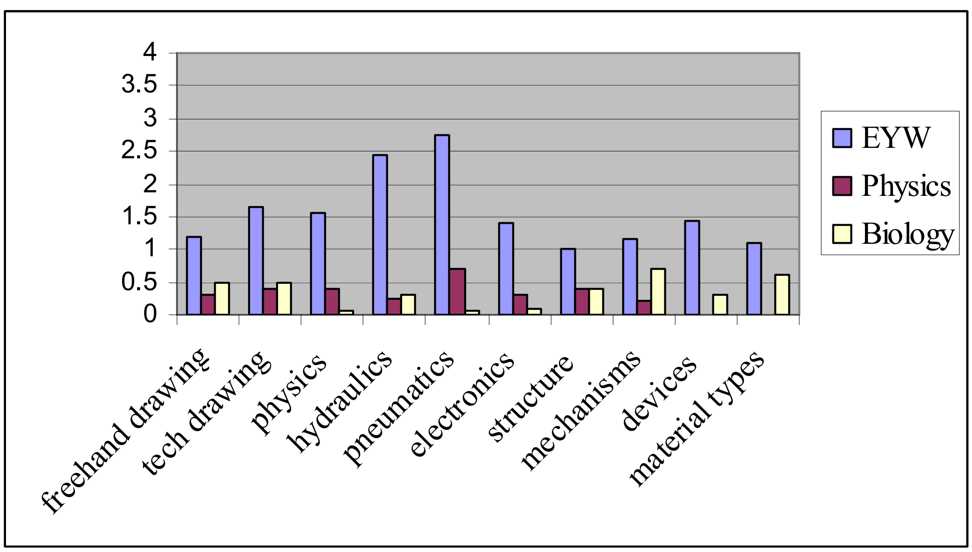

Figure 2. Pretest-Posttest Change in Concept Familiarity for EYW, Physics, and Biology Lab Courses

Adjective checklist. A 34-item adjective checklist containing 18 neutral, 8 masculine, and 8 feminine terms was analyzed to note presence and potential change of stereotypes toward engineering.

We compared adjectives circled by thermodynamics students to those circled by General Psychology students. As expected, a between subjects ANOVA indicated that psychology students (M = 1.33, SD = 0.97) circled significantly fewer female adjectives than the engineering students (M = 2.31, SD = 1.26), $F(2, 87) = 4.12$, $p < 0.05$. This replicates previous findings about engineering stereotypes often held by outsiders. Specifically, engineering is often perceived as a masculine field. There was no difference between pre-course and post-course (M = 2.07, SD = 1.44) perceptions of femininity among engineers.

We compared adjectives circled by *EYW* students to those circled by students in comparable biology and physics labs both at the beginning and the end of the courses. A multivariate Analysis of Variance indicated that there were no significant pre to post course differences in feminine terms circled, $F(1, 109) < 1$, or masculine terms circled, $F(1, 109) < 1$. Likewise, there were no differences between courses in the number of feminine terms circled, $F(2, 109) = 1.58$, $p < 0.05$, or masculine terms circled, $F(2, 109) = 2.56$, $p < 0.05$.

Interest. Students interest was measured through the question, 'My experience in this course has increased/decreased/maintained my interest in engineering."

Students indicated that the thermodynamics course maintained (57%) or increased (30%) their interest in engineering. Anecdotally, this seems quite good for a thermodynamics course! Students indicated that the *EYW* course increased (78%) or maintained (17%) their previous level of interest in engineering. We compared this result to responses from students in comparable lab courses in physics, for which 31% of students indicated an increased interest in engineering, and biology, for which no students indicated an increased interest in engineering. A chi-square analysis indicated that this is a significant difference in outcomes, $X^2(4) = 17.5$, $p < 0.05$ (see Figure 3).

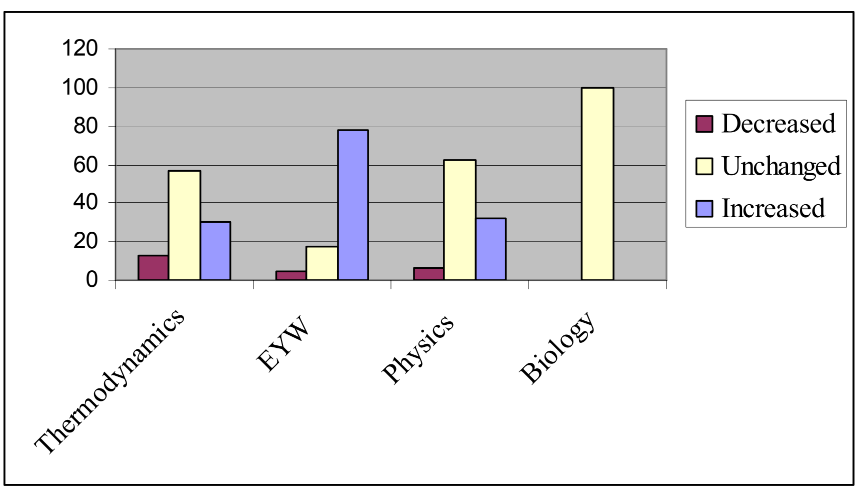

Figure 3. Engineering Interest Levels among Students in Thermodynamics, EYW, Physics, and Biology Lab Courses

Results for Conceptual Learning Tool

Conceptual vs. final exam comparison. We compared Thermodynamics student performance on the conceptual questions to their performance on a calculation-based final exam to determine whether the two different approaches were predictive of each other (i.e., concurrent criterion-related validity). A significant correlation between the two, $r = 0.46$, $N = 45$, $p < 0.05$, indicates that, indeed, students who performed well on the calculation-oriented exam also performed well on the conceptual exam (see Figure 4). While the two tests are not necessarily measuring the same thing, this is one piece of evidence supporting the use of conceptual questions as a proxy when knowledge of formulas is not required. This creates a fairer pretest, as students might 'get it' intuitively, without knowing the formal mathematical means for deriving answers.

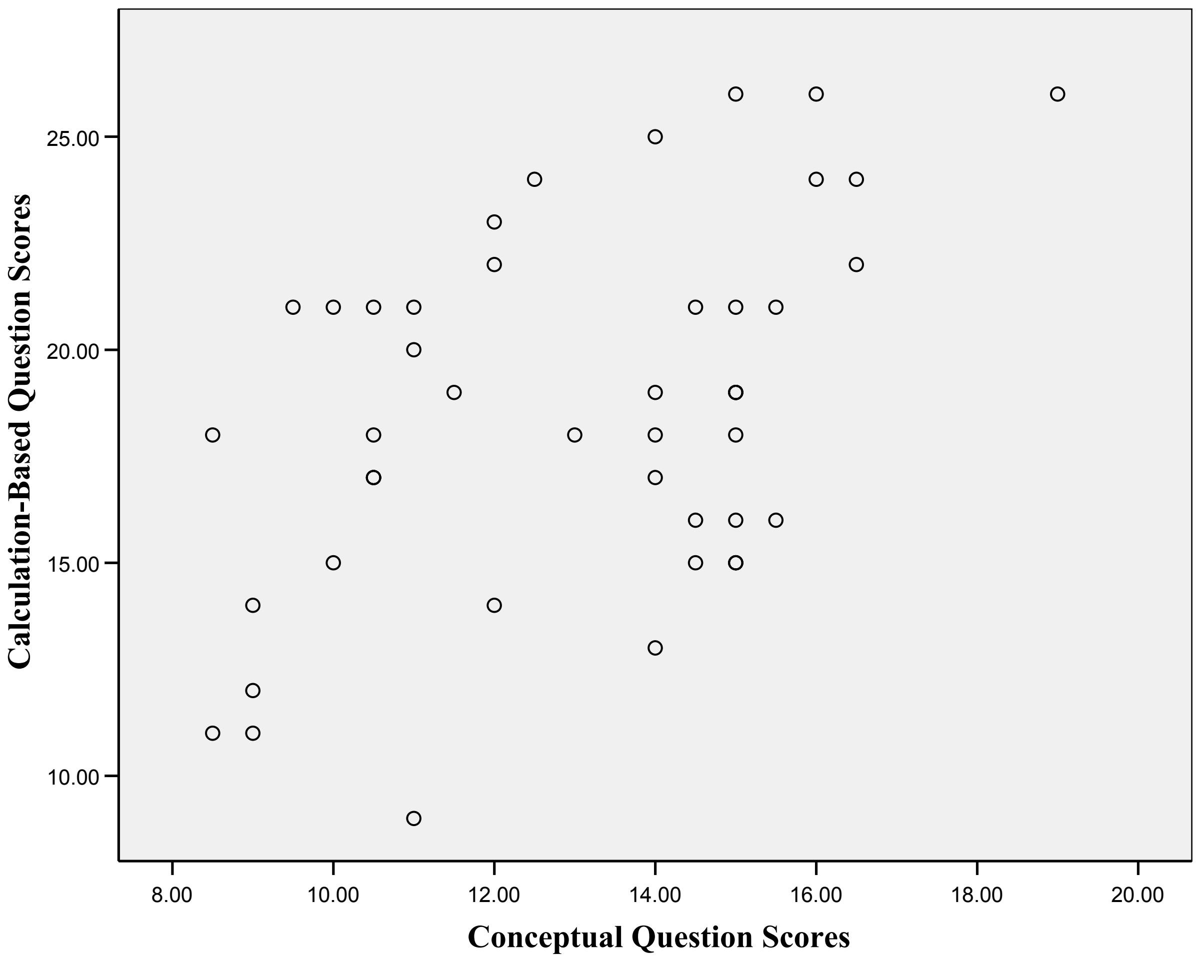

Figure 4. Correlation (r=0.46, N=45, p<0.05) between Conceptual and Calculation-based Exam Scores

Sex differences. Independent samples t-tests indicated that there were no differences between men ($M = 13.06$, $SD = 2.67$) and women ($M = 12.82$, $SD = 2.52$) in performance on the conceptual test $t(43) = 0.26$, $p > 0.05$. Neither was there a difference between men ($M = 18.4$, $SD = 4.02$) and women ($M = 19.09$, $SD = 4.83$) on the calculation-based final exam,

$t(44) = -0.47$, $p > 0.05$. This suggests that women understood as well as men by the end of the thermodynamics course. One caveat is that the small sample size minimized the power, which is the ability to find differences between groups. In order to add power to our analyses we will continue to collect data in future semesters. The data in this paper are representative of 3 semesters or approximately 65 students.

Comparison of lab sections (engine v. refrigeration) and projects. We hypothesized that the more hands-on experience students had with a topic, the better they would perform on questions targeting that topic. However, before conducting analyses of specific questions, we analyzed some general results to check for confounds. To provide some background, thermodynamics was structured as a lecture plus a lab. There were two different lecture sections and three laboratory sections. The three labs did not correspond to particular lecture sections. Lab sections were randomly assigned projects (two included refrigeration, solar, and turbine projects, the third contained engine projects only). To sort out the various influences of lecture section, laboratory assignment, and project, a regression analysis was performed with lecture, lab and project as predictors and overall test performance as the criterion. Regressions for conceptual and calculation-based tests were non-significant. This suggests that one lecture was no better than the other and that neither labs nor projects specifically affected overall understanding of thermodynamics.

The problem with overall measures is that they hide trade-offs such that one student may get all the engine-related questions correct but not the refrigeration questions, another student could do the opposite, and they could potentially end up with the same score. Thus, we separated the engine questions from the refrigeration questions and reran the statistics. An independent samples t-tests for differences by sex was not significant for refrigeration questions, $t(43) = -0.24$, $p > 0.05$, or engine questions, $t(43) = -0.12$, $p > 0.05$. An independent samples t-tests for the lecture sections was also non-significant for refrigeration questions, $t(43) = 0.42$, $p > 0.05$, and engine questions, $t(43) = -0.6$, $p > .05$. A multivariate Analysis of Variance indicated no significant differences by lab section for refrigeration questions $F(1, 38) < 1$, and engine questions, $F(1, 38) < 1$. Another multivariate Analysis of Variance indicated no significant differences by project for refrigeration questions $F(3, 38) < 1$, and engine questions, $F(3, 38) < 1$.

Based on the various analyses, it appears that there are no content-specific changes in knowledge based on specific laboratory or project experiences. These results failed to support our hypotheses. However, again it is possible that the low level of power due to small numbers in each lab or project did not allow us to pick up true differences.

Pre-post comparison. The 10 *EYW* students for which we had both pre and post data indicated a significant improvement on the learning test between pre and post testing. Specifically, a repeated measures t-test showed that posttest scores ($M = 1.91$, $SD = 1.14$) exceeded pretest scores ($M = 1.09$, $SD = 0.94$) by an average of almost one question, $t(10) = -2.76$, $p < 0.05$.

Comparison to bio/physics. Physics students ($N = 20$) began the semester with a significant advantage of almost one question ($M = 1.95$, $SD = 0.94$) over *EYW* students ($N = 19$; $M = 1.16$, $SD = 1.01$) on the learning pretest, $F(2, 66) = 3.21$, $p < 0.05$. Biology students ($N = 30$) were in between in terms of pretest performance (M = 1.53, SD = 0.97). A comparison of posttest score indicated that no differences existed between groups at the end of the semester, $F (2, 43) = 0.18$, $p > 0.05$. Table 4 and Figure 5 present the group means and standard deviations.

Table 4: Descriptive statistics for post-course learning test scores among Engineering in Your World, Biology, and Physics students

	N	Means	Standard Deviations
Pretest Scores			
EYW	19	1.16	1.01
Biology	30	1.53	0.97
Physics	20	1.95	0.94
Posttest Scores			
EYW	16	1.81	1.11
Biology	13	1.69	1.25
Physics	17	1.94	1.03

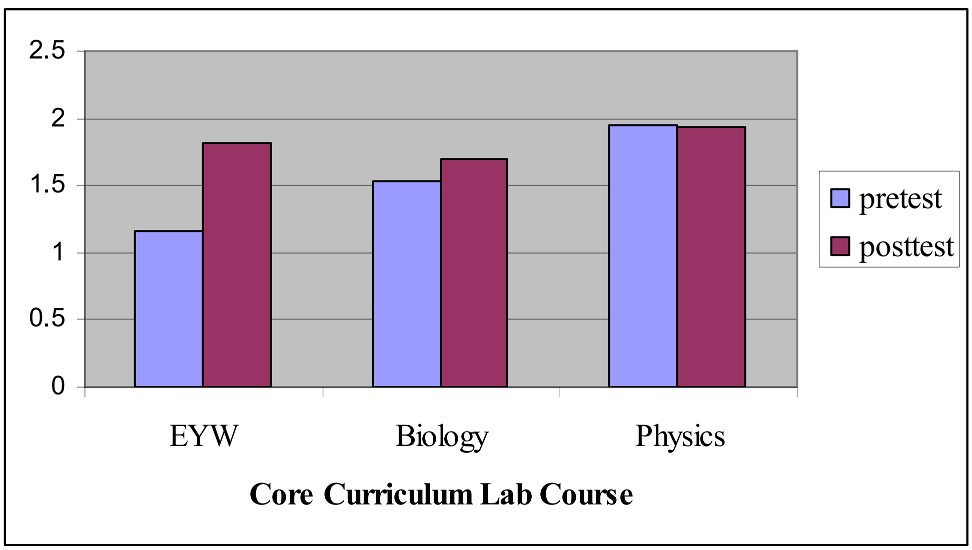

Figure 5. Mean Learning Exam Scores for Engineering in Your World (EYW), Biology and Physics Courses.

Results for Behavior Rubric

The tools have been developed, and we have spent two years attempting to obtain actual data. We attempted tracking student interns during the summer of 2005 and the fall of 2006. Three students responded. We contacted these students' internship supervisors to provide analysis of students' behavior during internships subsequent to taking the target courses. None returned the completed rubric, despite repeated requests and reminders. It has become painfully clear that there is not a culture among engineering internship supervisors to provide this kind of information at this time. An alternative idea for determining whether learning transfers to actual behavior would be to ask faculty of advanced engineering courses to assess students' thermodynamics capabilities using this same rubric.

Discussion

We attempted to measure comfort with and attitudes toward engineering due to the target courses through three different means: familiarity assessment, adjective checklists, and a general interest question. The familiarity assessment and interest question effectively denoted variations among people with different science and engineering laboratory experiences. Fine-tuning the wording (e.g., focus on familiarity and leave out "comfort with" since students may be familiar with concepts but not comfortable with relevant calculations) may lead to even more clarity. While the adjective checklist did pick up on differences between students inside and outside of the natural sciences, the checklist was not sensitive enough to pick up on potential changes due to engineering curriculum. The checklist needs additional analysis and perhaps modification. It will be important to investigate the impact of increasing the proportion of masculine and feminine adjectives checked compared with neutral adjectives.

The difference in perception between psychology and engineering students supports the notion that a reason for a lack of interest in engineering is systemic, starting with pre-college students and their teachers, who either do not know what engineering is or who avoid it based on their *negative perception* of what engineering is about[7].

In terms of learning, *EYW* students improved their scores slightly but significantly on the learning test. The other lab courses (physics, biology) that fulfill the same curricular requirement did not demonstrate the same improvement. Also, when compared to the other lab courses, *EYW* students began with slight but statistically significant lower scores but ended with comparable scores. This suggests that learning did occur among the *EYW* students and that several alternative explanations (such as historical events or academic maturation) have been eliminated.

Currently, a group of researchers are developing and validating conceptual measures focusing on frequently misunderstood concepts related to thermal and transport science[9] (e.g., energy vs. temperature, steady-state vs. equilibrium processes, rate vs. amount of transfer) and to mechanics and electric circuits[10]. Another conceptual tool that is still under construction but shows promise is the Thermodynamics Concepts Inventory[11]. These tools may be an effective supplement to the conceptual learning questions used in this project.

While we are pleased with the quality of the behavior rubric that we generated, we were disappointed with the disinterest in using it by both supervisors and graduates themselves. Perhaps a shift in normative behavior (behavior assessment becoming more common or accepted practice) needs to occur before people spend their time on this type of activity.

We believe our results support a three-pronged approach to assessing curricular effectiveness. Future research should expand the validation process. To test external validity, additional data collection should be attempted in various college and university settings. Internal consistency, construct validity and predictive validity of the measures should be tested as well.

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Appendix A: Post-Course Attitudinal Measure for Thermodynamics

List 5 adjectives you would use to describe an engineer.

Name 5 people who contributed to the technology we know today.

My level of familiarity and comfort with … **(check all that apply)**	Never heard of it	Heard of it	Know what it means	Have some ability myself	Know how eng'g relates	Expert at it
Turbines						
Nozzles						
Compressors						
Pumps						
Vapor Systems						
Combustion						
Refrigeration						
Heat Pumps						
Ideal Gasses						
Math concepts of integrals and differentials						
Physics concept of work						
Physics concept of energy						
Physics concept of heat						
Physics concept of closed systems						
Physics concept of open systems						
Physics concept of cycles						
Physics concept of enthalpy						
Physics concept of entropy						
Finding and using thermo-physical data						
Contemporary issues governing energy conversion						

Please circle/highlight any adjectives below that you would use to describe an engineer:

adventurous	committed	disciplined	intellectual	stressful
ambitious	cooperative	dominant	intuitive	strong
anti-social	credible	enterprising	inventive	submissive
anxious	dangerous	ethical	isolated	successful
assertive	dependent	independent	macho	tedious
authoritative	determined	initiative	professional	weak
caring	diligent	innovative	strategic	

What is the most significant idea you are taking away from this Thermodynamics course?

My experience in this course has **INCREASED/DECREASED/NOT CHANGED** my interest in Engineering.

Do you know any Mechanical Engineers? No Yes

If yes, how many and what relation are they to you (e.g., friends, acquaintances, specific relatives, etc.)?

Appendix B: Conceptual Learning Questions for Thermodynamics

1. What would happen to the temperature of a room in which a refrigerator was left running with the doors open?

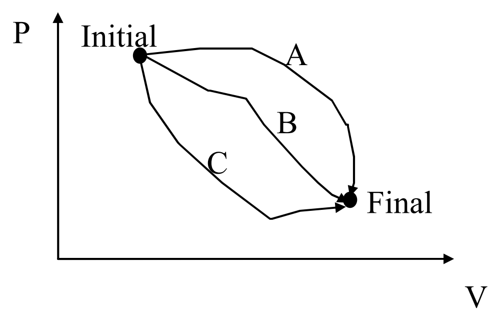
   i. The temperature of the room would decrease.
   ii. The temperature of the room would remain unchanged.
   iii. The temperature of the room would increase.

2. A power plant generates electricity using engines that burn fuel (e.g. coal) and provide power to electric generators. The thermal efficiency of the engines can not be 100%, because

   i. they must exhaust heat to the environment.
   ii. they must do work on the generators.
   iii. they require heat from the burning fuel.

3. What is wrong with the following statement? "Given any two bodies, the one with the higher temperature contains more thermal energy?"

4. Three identical gas filled cylinders each with a movable piston go from the same initial state of pressure and volume to the same final state. However, the three take different paths, as shown. On which cylinder of gas is the **least** work done?



(a) cylinder A
(b) cylinder B
(c) cylinder C
(d) All require the same work.

5. In solving a problem involving the pressures and temperatures of a gas, a student writes

$$P_1/T_1 = P_2/T_2$$

Which of the following must be true in order for this equation to be valid? (Circle all that apply.)

   i. Pressure of the gas is constant.
   ii. Temperature of the gas is constant.
   iii. Volume of the gas is constant.
   iv. Mass of the gas is constant.

6. How does the heat released in condensing steam compare to the amount of heat required in boiling the same mass of water?

   i. The amount of heat given off in condensing the steam is the greater.
   ii. The amount of heat required in boiling the water is the greater.
   iii. The two amounts of heat are the same.

7. If over break I were to clean up the clutter in my office, how would the entropy of my office and the entropy of the universe be affected?

i. The entropy of my office and the universe would both increase.
ii. The entropy of my office and the universe would both decrease.
iii. The entropy of my office would increase, and the entropy of the universe would decrease.
iv. The entropy of my office would decrease, and the entropy of the universe would increase.

8. An inventor claims that he has invented a gasoline engine that uses 100% of the energy generated in burning the gasoline. Which idea from thermodynamics makes this impossible?

i. During the operation of an engine, energy must be conserved.
ii. During the operation of an engine, entropy must increase.
iii. Gasoline is a poor quality fuel.

Appendix C: Behavior Rubric

Behavior Rubric-Supervisor/Teacher Assessment
Employee/Student Name and Affiliation:______________________________ Instructions: For each of the 11 performance dimensions (e.g., Apply knowledge...) please circle the category (e.g., needs improvement) of behaviors that best represents this person's behavior. While you may not have witnessed the behaviors exactly as written, please find the examples most analogous to what you have experienced. Please use N/A only in the case that you have not interacted with the person regarding that performance dimension.

	Needs Improvement	Competent	Exemplary
Apply knowledge of Math, Science and Engineering	~does not remember applicable math & science; ~remembers material, but does not know which concepts apply to problems	~remembers applicable math & science ~knows which concepts apply to problems	~can solve problems that require chains of concepts, or several steps
Design and Conduct Experiments	~misunderstands or vaguely defines questions to be studied ~over generalizes conclusions that can be drawn from the data	~identify key parameters that affect that question ~identify methods to vary the parameters they want to vary and maintain those they want stable ~determine accuracy of measurements (regarding repeatability and bias)	~can solve difficult problems, performing those behaviors demonstrated in "competent"
Design a System, Component or Process	~tends to approach different problems with a generic solution concept ~tests solutions superficially	~can identify requirements of a system (ex. what it needs to be able to do) ~develops a concept for a solution ~apply knowledge to implement the solution ~able to take test results & modify design	~considers a broad range of possible solutions ~solve sufficiently complex problems (ex. those that require subcomponents to be solved)

	Needs Improvement	Competent	Exemplary
Function on Multidisciplinary Teams	~when problems arise, delays bringing them to the attention of the group ~assigns tasks based on convenience rather than according to others' skill sets ~could be expected to miss deadlines that affect other group members	~completing tasks assigned to them competently (in regards to above behaviors) ~in assignment of tasks, communicates both strengths & weaknesses ~recognizes when communication is not working well ~deals with conflict by attempting to resolve it in a way that is satisfactory to everyone ~responds to failure of coworkers in a way that increases the chance of success within the team ~checks in with others regarding their parts of the project	~integrates contemporary issues into discussions and projects ~sees trends rather than discrete events ~identifies connections between information from various sources ~initiates discussion of strategy and resource organization
Identify, Formulate and Solve Engineering Problems	~dwells on minor details, missing big picture issues	~draws diagrams showing connections	~lists the known, unknown and assumptions
Professional and Ethical Responsibility	~takes credit for others' work ~does not meet commitments ~claims expertise in areas they don't know anything about ~works against interests of the team and only for themselves ~ignores regulatory, environmental, & safety issues in design	~follows regulatory, environmental, & safety issues in design (ex. manufacturability, recyclable materials, sustainability, safety) ~avoids conflicts of interest	~identifies regulatory, environmental, & safety issues where others do not ~looks beyond surface issues (especially when surface looks acceptable) to find and fix problems ~avoids even the appearance of conflicts of interest

	Needs Improvement	Competent	Exemplary
Communicate Effectively	~does not consider audience by using jargon and too many details when talking to lay people (ex. clients)	~clearly sketches out ideas (ex. block diagrams of logic, circuits, etc.)	~summarizes by picking out most critical elements of problem
Understand Global and Societal Impact of Engineering	~only considers first order effects of what they are doing	~understands first and second order effects of what they are doing, within a society they are familiar with	~actively gains an understanding of a different society so as to understand the societal impact on that society (understands first and second order effects of what they are doing *in another* society) ~thinks of indirect consequences (outside first & second order effects)
Lifelong Learning	~relies primarily on previous education and experience to solve problems	~does independent research to answer questions ~asks questions ~can be critical of information they find	~seeks out questions of their own and do research (versus being presented a question to do research for) ~pursues continuous process improvement
Knowledge of Contemporary Issues	~unaware of current events ~sees isolated events rather than trends	~maintains connection with industry through professional publications ~understands global impact by keeping abreast of mass media	~integrates contemporary issues into discussions and projects ~sees trends rather than discrete events ~identifies connections between information from various sources
Use Techniques, Skills and Modern Engineering Tools	~seems unfamiliar or uncomfortable with current technology (ex. CAD)	~able to complete assigned problems requiring use of the necessary technology	~identifies on their own the need for and appropriateness of necessary technology