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What makes faculty adopt or resist change in engineering education?

Dr. Donna M Riley, Smith College

Donna Riley is Associate Professor of Engineering at Smith College.

Victoria Henry, Smith College
Lucia C Leighton, Smith College

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1 Introduction

Certain leaders in engineering education have signaled the reification of engineering education as a "rigorous" research discipline,[1,2] and a resulting gap has widened between "researchers," who often do not teach technical core courses, and "practitioners" who do. There have long been many engineering educators who do not attend ASEE meetings are not members of the organization; however, this new gap seems to split many practitioners of engineering education who are involved to varying degrees in engineering education research, from a new cadre of scholars who exclusively conduct research in engineering education, or who otherwise fit with the new orthodoxy.

Be that as it may, in recent years, there have been calls for focus on bridging the gap between research and practice in engineering education,[3,4] building on economic research on analogous gaps in the R&D invention-to-innovation transition.[5] Auerswald and Branscomb[6] cite "asymmetries of information and motivation, as well as institutional gaps" operating in the private sector. Examples of these include: differing motivations and reward structures for original research versus its application; different cultures, training, expectations, information, and communication modes between technologists and managers; gaps in funding sources; and institutional and structural obstacles to dissemination.

One pertinent question in addressing this issue is what factors influence engineering educators' decisions to adopt or resist particular changes in engineering education, especially those based on results of engineering education research. Spalter-Roth and colleagues[7] identify a set of factors influencing the adoption of innovations including faculty reward structures and roles in research as compared with teaching. They additionally identify sociological factors including the specific realities of organizations, institutions, and social networks, all of which operate to encourage or discourage adoption. Status hierarchies and professional norms vary by department and institution. Karan Watson[8] further observes a communication gap in which researchers "do not always translate their foundational findings into applications that can be used in the classroom or by curriculum committees." Considering individual, departmental, and administrative decision-making as contributing factors provides a more complete picture of obstacles to innovation.

Researchers have begun to explore strategies for investigating and resolving barriers to dissemination. Spalter-Roth et al.[7] lay out a research agenda that recommends mixed method (or multi-method) study designs as the most robust approach for capturing information about how these multiple factors operate to influence adoption of engineering education innovations. Watson[8] also recognizes the role of multiple factors when she states, "it is going to take course changes, content changes, pedagogical changes, organizational changes, structural changes, and cultural changes to realize systems to educate the engineers of 2020." She further argues that communication and collaboration across the researcher-practitioner divide is essential to progress.

2 Approach

2.1 Overall Study Design

Our overall study design was a multiple methods approach consisting of (1) a mostly closed-ended survey of thermodynamics instructors at ABET-accredited engineering programs in the US; (2) open-ended surveys/reflections of practitioner collaborator-consultants, recruited from among survey participants to implement engineering education innovations in their thermodynamics courses; (3) open-ended surveys/reflections of student participants in courses where engineering education innovations were implemented; and (4) qualitative analysis of student work in these courses. In this paper we will focus on preliminary findings from (1) and (4). Student performance is not a direct measure of faculty adoption of innovation, but it does provide a sense of the extent of transformation, readily acknowledging that multiple factors affect transformation including faculty innovation, the effectiveness of the innovations for producing change, student motivation, and more.

2.2 Recruitment and Sampling

We surveyed thermodynamics instructors at ABET-accredited institutions. A database of 340 thermodynamics instructors was developed from course information on University websites (most often with one instructor listed per institution). Instructors were invited to participate by email with one follow-up email. 44 of the 340 responded, with women overrepresented in the response pool (35% of respondents as opposed to 12% of invitees). This was the only significant difference between the sample and the population, though we expect a self-selection bias in that respondents who participated were likely more interested in participating in an engineering education study than those who did not. This could translate into a different set of attitudes toward engineering education research than for non-participants.

All survey participants were invited to participate in research on the effectiveness of course modules found in the book *Engineering Thermodynamics and 21st Century Energy Problems: A Textbook Companion for Student Engagement*[9] by incorporating one or more modules into their pre-existing curriculums in their thermodynamics classes. Adopters were offered $1000 compensation for their role as consultant-collaborators in the study. In return, adopters agreed to 1.) Incorporate one or more modules into a thermodynamics course, as appropriate for their particular course setting and student population; 2.) Elicit student feedback on the module, adapting assessment materials as needed to the instructional context (materials include student self-assessments integrated in the reflective portion of the modules and instructor-administered minute-papers or short surveys to identify aspects that worked well and aspects that require change); and 3.) Evaluate their own extent of adoption, and suggest changes to the module based on student evidence and other evaluation data they have gathered. This faculty assessment of the modules can be used to improve the e-book dissemination tool as well as the dissemination process itself. Results of faculty assessment are not yet analyzed and thus are not part of this paper.

As part of the study design, adopters were not asked to attend training in critical pedagogies, even though it was apparent to us that such training would likely produce a more transformative approach to the work. The study sought to characterize the dissemination process with day to day practitioners in engineering education, faculty likely too busy for (or uninterested in) such a training. Because we were seeking to identify factors in adoption of innovations, we needed to minimize the extent of intervention with the faculty adopters. Thus we did not train them in the use of the pedagogies, and we did not offer incentives beyond the financial, where again some less conventional incentives might have produced greater change.

Of the 44 survey respondents, 20 volunteered to be collaborator-adopters. Of these volunteers, 8 completed adopter requirements (i.e. implemented and evaluated modules and participated in the collaborator survey) and 4 of these additionally provided samples of student work. Course modules were implemented at a diverse range of educational institutions: four large state universities in the South, Southwest, and Midwest, a community college in the Northwest, a private university in the upper Midwest, and an HBCU. Additionally, a small sample of student work from the textbook author/PI's institution was included for comparison.

The low participation and high attrition rates are clearly problematic. It may be that a number of invited faculty are not interested enough in engineering education research, or simply do not feel they have the time (or are not rewarded for time invested) participating in the survey (which did not offer compensation).The attrition rate suggests that with such a significant workload for collaborators, $1000 incentive does not actually compensate faculty for the time involved in revising a course to include a module, teach that module, and then evaluate it. But to offer larger incentives in a research study introduces ethical problems of undue inducement to participation. While the sample size was small, there was a broad diversity of participants by institution type, size and geography, as indicated in Table 1.

2.3 Thermodynamics Instructor Survey

Thermodynamics instructors (n=42 in this section) were asked to rate their agreement or disagreement with a number of statements intended to characterize their attitudes, motivation, and experience with engineering education research as well as their home institution's support for engineering education research and creative teaching practices. The survey includes statements such as, "Current thermodynamics books are out of date and lack current material relevant for today's engineers", or, "My institution rewards my adopting others' innovations in engineering education."

Instructors then participated in a ranking exercise identifying the relative importance of nine factors (derived from the literature) influencing faculty decisions to incorporate engineering education research in their practice. Faculty ranked the 5 most important of the nine in numerical order, and left the four items deemed least important unranked.

Data were coded as appropriate for each type. Background data were tallied to obtain a demographic profile of the sample, measuring characteristics like tenure status, ASEE membership, years of experience, and the like. The second survey section measured attitudes toward educational innovation on a Likert scale; these data were assigned numerical values aligned with higher number indicating higher propensity to innovate (i.e. some items were reverse coded per study design). Ranking data were assigned numerical values with the greatest value assigned to those ranked most important, and 0 assigned to those left unranked.

Table 1: School profiles completing module implementation and evaluation[10]									
	North East College (A)*	South East State (B)	HBCU (C)	Mid West Univ (D)	South West State (E)	Midwest Tech (F)	South West Univ (G)	Mid West State (H)	North West Comm College (I)
Level	4-year	4-year	4-year	4-year	4-year	4-year	4-year	4-year	2-year
Control	Private	Public	Public	Public	Public	Private	Private	Public	Public
Population	<5000	<5000	<10,000	>30,000	<10,000	<5000	<5000	>30,000	<5000
Instruction Program	A&S	Prof+ A&S	Prof+ A&S	Prof+ A&S	Balanced	Prof	Balanced	Balanced	Assoc-iates
Graduate Programs	Single Doc	Single Doc	Doc/ Prof	Comp Doc	Single Doc	Postbac Prof	Prof./ Doc	Comp Doc	N/A
Undergrad Profile	Full time more selective	Full time inclusive	Full time inclusive	Full time more selective	Full time selective	Full time more selective	Full time selective	Full time inclusive	part/ full-time
Residential	high	high	primary	primary	primary	primary	high	no	2-year
Research	Liberal Arts	Doctoral	Larger Master’s	Very high	Larger Master’s	Medium Master's	Larger Master’s	Very high	Assoc.
Schools labeled A-F supplied samples of student work; the other three schools participated in student and faculty reflections only.									

2.4 Analysis of Student Work

Sets of student work from the four institutions who supplied them were analyzed qualitatively. The institutions included three state universities (one an HBCU) and one private liberal arts college.

2.4.1 Assignment Descriptions

Student work reflected assignments from 12 of the 20 course modules offered in the textbook (Table 2), three exclusive to the home institution that originated the modules.

Table 2: Modules

Number	Title	Schools Completing	Samples of student work	Student Survey Responses
1.1.1	Thermodynamics is About Energy.	B, H	15	17
1.3.1&3	US and World Energy Needs and Uses	D	11	48
1.5.1	Power/Knowledge	A	<3	N/A
2.2.1	Technology Selection for Energy Independence:	A	<3	N/A
2.3	Evaporative Cooling	F, I	1 (team)	30
2.4.	Hunger, Poverty, and Obesity.	A, E	4 (teams)	12
3.1	Limits of Efficiency	C, G	3	6
3.2	Perpetual Motion.	C	3	1
3.3	Entropy: Origins and Implications.	C	3	1
3.4	Entropy Analogies in Textbooks	C	3	1
3.5	Making Math Relevant: Thermodynamic Relations in Context.	C	3	1
4.5	Ethics of Energy Disasters	A	<3	N/.A

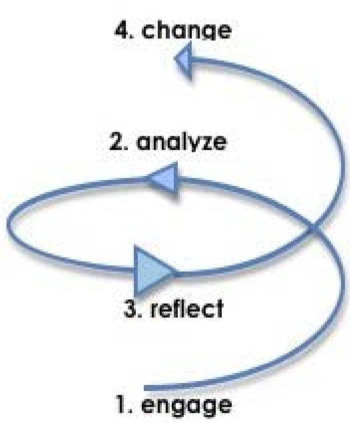

Figure 1: Learning Process

All course modules require students to follow the textbook's unique "Engage, Analyze, Reflect, Change" model (Figure 1). Each module is designed to address multiple non-technical ABET outcomes.

In Module 1.1, students were encouraged to explore and develop their own definitions of energy prior to doing any further research or consulting a technical definition. They are then asked to utilize their information literacy skills to attain various definitions of the term "energy" from outside sources. Finally, they are asked to consider the similarities and differences they see between the different definitions, and to develop a new personal definition of "energy." They are then asked to repeat the assignment with the term "thermodynamics."

Module 1.3 focuses on United States and world energy needs and usage. The university utilizing Module 1.3 chose not to complete section 1.3.2, a portion of the Module entitled "Women, Poverty, and Energy," thereby neglecting the portion of the chapter that focuses on gender issues.

In Module 1.5.1 students read an excerpt from Foucault on truth and power in science. They are then asked to consider Foucault's conception of power in relation to contemporary institutional power structures, specifically those found in the field of engineering.

Module 2.2.1 requires students to watch a segment of the Rachel Maddow show in which she discusses the concept of foreign oil independence as a myth. Students are then asked to consider their own dependence on oil and imagine the impact it would have, both practically and politically, if the United States began to produce the entirety of its oil domestically. Finally, students are asked to consider the structural changes they see as necessary for the United States to achieve independence from foreign oil and evaluate the role engineers play in this process.

Module 2.4 focuses on Hunger, Poverty, and Obesity, with students visiting local markets to measure energy cost and energy density of food, comparing access to low energy-density food like fruits and vegetables vs. high-energy-density processed foods based on socioeconomic status.

Modules 3.1-3.5 focused on the second law and were undertaken as one assignment at a single site. Module 3.1 explores the limits of efficiency in heat engines based on Carnot Principles while exploring how both the limits of efficiency and very meaning of efficiency changes when one considers hydro or solar power. Module 3.2 introduces historical and present-day controversies over perpetual motion, asking students to reflect on power and knowledge in science. Module 3.3 presents the origins of entropy as a concept in 19th century Western Europe, and explores the reasons for its development as well as its philosophical implications. Module 3.4 asks students to take a critical look at their textbook's presentation of analogies for entropy such as messy rooms, disordered libraries, and the like, and evaluate what is useful and what is unhelpful about those analogies for developing understanding of entropy. Module 3.5 is an open-ended assignment in which students write about a personally resonant application for the the thermodynamic relations.

2.4.2 Coding

The authors developed a coding system[11,12] for analyzing the student work portion of the project's qualitative data. According to MacQueen and colleagues,[13] "the codebook functions as a frame or boundary that the analyst constructs in order to systematically map the informational terrain of the text" (p. 32). In keeping with this philosophy, codes were developed to illuminate central questions of the study, allowing researchers to determine how often codes occurred, in what context, and their significance. The final codebook—consisting of 21 codes—was developed as the result of extensive reading and exploration of the recurrent themes, patterns, and concerns found in the student work.

Two of the authors were engaged in the work of coding the data, including the development of the codebook. To ensure intercoder reliability, each code was clearly defined including a short title, a comprehensive definition, and an example (taken from student work) of when to use the code. Inter-rater reliability testing was performed using student assignments selected randomly from all three educational institutions. Inter-rater reliability testing yielded identical coding over 77 % of the material.

3 Survey Results

3.1 Survey Information

Forty-three participants responded to the 36 question survey measuring faculty beliefs and attitudes toward engineering education innovation. Table 3 shows background data on the sample.

Table 3: Background data (n=42)

Institution	Public 60%	Private 40%		
Years Teaching	<5 16.7%	5-10 26.2%	11-20 33.3%	>20 23.8%
Rank	Full 28.6%	Associate 50%	Assistant 16.7%	Other 4.8%
Tenure	Tenured 70.7%	Not 29.3%		
ASEE	Member 47.6%	Not 52.4%		

3.2 Statistical Analysis

The main purpose of the survey was to discover what makes Engineering educators want to adopt new methods of teaching, specifically Engineering Education methods. We were interested in how rewards structures, both tenure and promotion and other types of monetary rewards or non-monetary recognition, influence the adoption of novel teaching methods. We were also interested in measuring the potential impact of institution type, faculty attitudes toward innovation, faculty rank, and familiarity with the engineering education field.

The survey was developed based on a literature review of factors affecting innovation in higher education and in engineering education, with the Spalter-Roth[7] report being the most comprehensive. The survey is original to this project, as there are not existing surveys specific to these research questions. Because the focus population was engineering thermodynamics professors, it is unlikely that this survey is generalizable to any significant extent.

Questions from the survey were organized into five cluster themes: 1) Attitude Towards Thermodynamics Textbooks, 2) Institutional Support of Innovation, 3) Innovation of teaching methods, 4) Knowledge of Engineering Education, and 5) Institutional prioritization of teaching. Survey questions with directionally negative content were reverse coded and the clusters were then measured for internal consistency using Cronbach's alpha. Cluster 5, "Institutional Prioritization of Teaching Methods" revealed a poor alpha score of .419 and thus was eliminated along with several other questions that proved to reduce the internal consistency of the clusters. The "Textbooks" cluster revealed an alpha score of .770 and included questions such as, "Current thermodynamic textbooks are out of date and lack current material relevant for today's engineers." Cluster two of the survey, "Institutional Support of Innovation" (**a=** .876) included questions such as, "My institution provides compensation or recognition for innovative teaching", and “My institution rewards my own research in developing engineering education.” Cluster three, “Innovation of Teaching Methods” (a= .706), included questions such as, “I teach my course the way it was taught to me” and “I change my teaching methods.” “Knowledge of Engineering Education”, the fourth and final cluster (a=.872), included such questions as, “I do not have time to read about engineering education research”, “I find engineering education research doesn’t really apply to my courses”, and “I use findings from engineering education research to improve my courses”. Those survey questions that did not fit within a cluster, or revealed poor alpha scores included questions such as, “I write my own homework problems”, and “I repeat assignments and lectures from previous offerings of my course”. These questions were eliminated from further analysis because they were deemed no longer of particular relevance to our research questions. At the same time, we considered two items that related quite directly to our research question as individual variables in the relationship and correlational tests: “I would be willing to adopt engineering education innovations if my institution gave me compensation or recognition for doing so”, and “I am willing to adopt engineering education innovations without institutional compensation or recognition for doing so.”

Due to our response rate and sample size, we used the non-parametric Mann-Whitney test to compare the clusters of survey responses to the factors we predicted would affect willingness to innovate, namely, Tenure status and ASEE membership. Results revealed that only “Knowledge of Engineering Education” was significantly related to Tenure status (p=.003). This indicates that those with Tenure are more likely to be knowledgeable about Engineering Education and to be involved in innovations in Engineering Education. There were no other significant relationships between Tenure status and the three other clusters and the two willingness to innovate variables. We ran a second Mann-Whitney test, to look at the relationship between our clusters and ASEE membership. Results revealed that “Knowledge of Engineering Education” and ASEE membership were significantly related (p=.001), as well as ASEE membership and “Innovation of Teaching Methods” (p=0.65)*. These results suggest that ASEE members are more familiar with the field of Engineering Education and more likely to practice innovative teaching methods (see Table 4).

Table 4 Correlation Coefficients for Relationship Between Cluster Themes and ASEE Membership or Tenure

	ASEE Membership	Tenure
Attitude Towards Textbooks	.129	.315
Perceived Institutional Support of Innovation		
Attitude towards Innovative Teaching Methods	.112	.284
Knowledge of Engineering Education	.067*	.284
Willingness to Adopt with Compensation	.001***	.003**
Willingness to Adopt without Compensation	.180	.349
	.230	.412

Note * p < .1, ** p<.05, *** p<.001

Spearman- Rho correlation (employed because distributions were non-normal) revealed that “Institutional Support of Innovation” was significantly correlated with “Knowledge of

Engineering Education" (p=.001 ρ=0.499). Willingness to adopt without compensation or recognition was positively but not significantly correlated with knowledge of Engineering Education. These results indicate that faculty who perceive their institution supports innovation are more likely to be involved in Engineering Education, and that knowledge of engineering education is related to willingness to adopt Engineering Education innovations without institutional compensation or recognition.

3.3 Ranking Results

In the ranking exercise, respondents rated 1-5 the most to least important factors, leaving four responses that they deemed least important blank. We reversed these values, giving the item ranked 1 a value of 9, 2 an 8, and so on, and the unranked items each received a 0. Results are shown in Table 5.

Table 5: Mean Ranks for Factors influencing Faculty Adoption of Innovations (N=39)			
Factor	Average Rank	Times Ranked	Respondents Ranking
Adopting innovations does not help faculty achieve tenure, promotion or merit raises	7.19	76	36
Faculty are not monetarily compensated for time spent adapting materials and changing courses	5.49	106	30
Faculty are not aware of research about engineering education	5.34	60	23
Technical research societies/colleagues do not value the adoption of educational innovations	4.94	70	22
Department/School/College does not value educational innovations (thanks and "good citizen" recognition)	4.67	82	22
Engineering education research innovations do not address specific problems in course content, student learning, or teaching	4.44	47	16
Students resist non-traditional content and teaching methods	4.40	49	16
Faculty are not internally motivated to be effective teachers	4.30	46	15
Institution does not support the adoption of innovation with stipends or small grants	4.23	49	15

In the ranking exercise, the highest ranked factor was "Adopting innovations does not help faculty achieve tenure, promotion, or merit raises." 92% of respondents rated this response in their top five. The second highest ranked factor was that "faculty are not monetarily compensated for time spent adapting materials or changing courses," with 77% ranking this factor in the top five. This emphasis on institutional factors pervaded responses regardless of the participants' level of involvement with or exposure to the engineering education research community, or assessment of the value of engineering education research. 59% placed low awareness of engineering education research in the top five ranked factors; here those less familiar with engineering education research tended to rank this factor more highly.

A Friedman test ($\chi^2(8) = 50.885$, p=.000) showed that the means were significantly different from each other. Post-hoc analysis using separate Wilcoxon Signed-Rank tests with a Bonferroni adjustment (significance level of p <.1 becomes p<.011 due to multiple comparisons) showed that the only significantly different mean was for "Adopting innovations does not help faculty achieve tenure, promotion or merit raises" against each and every other factor (p=.001 and lower).

We followed this analysis with a Mann-Whitney U-Test for both Tenure status and ASEE membership to see if there were any differences in how tenured and non-tenured participants ranked these factors, or in how ASEE members and non-members ranked the factors. Tenure status significantly affected the ranking of two factors: "Department/School/College does not value educational innovations (thanks and "good citizen" recognition)" (p=.09; tenured rank this higher) and "Institution does not support the adoption of innovation with stipends or small grants" (p=.045; tenured rank this lower). One possible explanation for these differences is that other kinds of recognition may become more important to faculty after tenure, and that small stipends and grants are more meaningful to faculty who are pre-tenure or non-tenure-track, perhaps because of career stage or salary level.

ASEE membership affected the ranking of "Students resist non-traditional content and teaching methods" (p=.035), and "Engineering education research innovations do not address specific problems in course content, student learning, or teaching"(p=.061), where ASEE members ranked each of these higher than non-members did, perhaps because ASEE member are more acutely aware of each phenomenon.

These results suggest that the most effective routes to supporting change in engineering education would come from a focus on institutional factors, particularly reward systems for faculty.

3.4 Open-Ended Responses

At the end of the survey there were open-ended questions that prompted respondents to provide additional factors not included in the ranking exercise, changes that would encourage faculty adoption of innovations, and "anything else you'd like to tell us."

Out of 17 respondents who commented, 8 brought up the issue of time pressure on faculty as a missing factor in the ranking exercise. We did not include time deliberately in the survey because we felt that time ultimately boils down to priorities. Given that time is always finite, faculty must make time allocations based on their priorities, balancing demands from students, departments, and the institution as well as their own projects. Since we cannot grow time, we must address the time issue by changing priorities.

Four respondents commented to the effect that engineering education research does not produce useful innovations (despite one of the factor choices being "Engineering education research innovations do not address specific problems in course content, student learning, or teaching"):

> "My own perspective is that I have never seen an educational research program that I considered valid."

> “Much of the research on education is "academic" with little relevance to actual practice.”
>
> “…innovations have not remarkably improved student performance.”
>
> “The problem with most engineering innovations is that they are not useful. So why would we adopt them.”

While this appears to be a small number of respondents overall, it does constitute nearly a quarter of those responded to the open-ended questions. This may be a more common view than even this sample suggests, given the low response rate and likely self-selection of respondents, to say nothing of the normative expectations of a survey *about* engineering education research innovation. This suggests that engineering education researchers have more work yet to do in communicating the value of our work to colleagues. Indeed the solutions proposed by this set of responders for improving adoption of innovations underscore this point, as they included “stop funding all the research,” and “stop advertising things as research-based…Certainly, an effective teacher is open to considering new ideas, but basing the decision on what educationists call research is silly.” Survey respondents expressing these extremely negative views are clearly not the ones who ultimately became adopter-collaborators. Their responses provide some insight into how the peers of educational innovators view the work of their colleagues, and the kinds of challenges innovators may face when these predispositions are present in reviews for tenure and promotion, among other interactions between faculty member and institution.

Two of the open-ended survey comments echoed this issue of faculty reward systems, noting that not only is teaching not rewarded in tenure decisions, educational innovations can even be a detriment to one’s tenure case. They further noted, “There's also a lack of respect for engineering education journals. It would be nice to see the high impact journals in the various fields of engineering also publish education articles.” Another spoke of the need to cultivate “a culture of excellence” around teaching at their institution.

4 Results from Qualitative Analysis of Student Work

We analyzed student work from four out of six schools who supplied us with samples of student work in completion of their modules (this is a work in progress). It is impossible to compare across assignments, courses, and institutions, so we do not make that attempt here. Rather, we report on what we observed of student performance across a number of codes related to liberal education: information literacy, communication skills, engagement, original thought, personal experience, social/economic context, and criticality. We chose these codes because a primary objective of the textbook project and subsequent dissemination efforts was to integrate liberal education learning objectives into traditional engineering thermodynamics courses.

While we discuss student performance related to these codes, it is important to emphatically state that our intent is not to blame to student for their performance in any area. Rather we are interested in what this performance can tell us about the design of the modules, faculty instruction, and dissemination of innovation in engineering education research.

Specifically, the modules develop the following intellectual and practical skills, as put forth by the Association of American Colleges and Universities' (AACU) Liberal Education Learning Outcomes: 1.) Inquiry and analysis, 2.) Critical and creative thinking, 3.) Written and oral communication, 4.) Quantitative literacy, 5) Information literacy, and 6.) Teamwork and problem solving. The modules also foster the development of the following personal and social responsibility outcomes: 1.) Civic knowledge and engagement (local and global), 2.) Intercultural knowledge and competence, and 3.) Ethical reasoning and action (AACU).

The research took place at a diverse range of educational institutions. School A is a small liberal arts school in the Northeast, and home to the largest all women's engineering program in the nation. It is also the home institution where the textbook was developed. The samples used in cohort A represent work thermodynamics students undertook independently, directly using the textbook, as extra credit or as makeup work. These were chosen because there was minimal intervention from the instructor, although the context of their education is not only steeped in a liberal education tradition, but also infused with critical pedagogies in the thermodynamics class itself. Schools B, C, and D are all large public universities located in the southeast, southwest, and Midwest. One of these is an HBCU and one is an elite selective institution. One goal of the research is to consider how textbook translated into different institutional contexts, and why.

The *Information Literacy* code was applied when students used (and properly cited) an outside source to define or explain a concept. This code occurred frequently (20 times) in the student responses to Module 1.1, completed by school B. In this lesson, students were asked to develop an individual definition of energy without consulting a technical definition. They were then required to utilize their information literacy skills by consulting multiple outside sources to attain technical definitions of the term "energy." In this Module, the information literacy code was applied when students quoted a definition from an outside source and satisfactorily cited that source (one of Module 1.1's specified requirements). Each student in the group that completed Module 1.1 (a group of 15) received the Information Literacy code at least once—and often two or three times—in his or her assignment. The *Information Literacy* code also appeared frequently in student work from school A (19 times). Students from school A completed a variety of different modules: Module 1.5.1: Power/Knowledge, Module 2.2.1: "Foreign" Oil Independence, Module 2.4: Hunger, Poverty, and Obesity, and Module 4.5: Ethics in Energy Disasters. These modules required students to consult contemporary sources such as "The Rachel Maddow Show," an essay by Michael Pollan, and relevant articles from the *New York Times*. The *Information Literacy* code appeared 12 times in the student work from School C. This school also completed Module 2.4: Hunger, Poverty, and Obesity. The *Information Literacy* code appeared just 11 times (out of 21 total assignments) in the student work from school D, which implemented Modules 1.3.2: Energy Use, and 1.3.3: 1kW per Capita. Both modules required students to obtain data from an outside source.

Though the *Information Literacy* code appears in the student work from each of the four schools, there is a lack of consistency in the quality of students' citations. While some students provide full citations (complete references), other students cite only a web link and fail to provide further reference information per standard style guidelines, or rely on Wikipedia (one student cites wikipedia (providing only a weblink) for six consecutive definitions). Inadequate citations were particularly common in the student work from schools B and D. The code appears in the student work from school D in approximately half of the assignments (and always in the form of a weblink), despite the fact that students were explicitly required to obtain data from an outside source. The other half of these students presented data with no citation whatsoever. However, though we observed variation across schools, it is impossible to determine whether these are due to differences in preparation levels of students, course difficulty, institutional culture, faculty expectations, or some other cause.

Regardless of the quality of citations, the frequency with which the *Information Literacy* code appeared in the student work proves that the nature of the textbook's assignments prompts students to engage with contemporary sources in order to gather information about critical issues. Through consulting a diverse range of non-traditional sources, students are able to develop better-informed and less biased opinions, encouraging the development of socially conscious engineers.

Because all assignments involved written work, communication skills were exercised by every student in every module. What jumped out for us in coding were extreme cases of poor writing, including incorrect grammar, typographical errors, extremely convoluted language, or any other case in which the student failed to articulate her/his thoughts and ideas. The following examples from student work illustrate instances in which this code was applied:

> "Also thermodynamics is the study on energy on a system so u have to consider the system itself that where engineering comes into play." —B8
>
> ". . . textbooks are called engineering thermodynamics because different idea had and have to be developed and engineered to take heat from one of its many properties and change into one or more of the others, then use that energy to power of give life to something." —B9

Even instructors who demand quality writing from students occasionally encounter poorly formed sentences or ill-structured reports. However, some of the samples we encountered cause us to ponder anew both what writing skills our institutions can expect from incoming students, and how our institutions can best assist engineering students in developing adequate writing skills before they graduate. At a minimum, these modules required students to express thoughts in words. Not all of the assignments received had been graded, so it was difficult to tell what kind of feedback students received regarding their writing. This is clearly an essential component for ensuring students are able to improve their communication skills; at this level, one has to believe that even the most technically-oriented professor can be of some assistance by correcting problems in writing.

This raises the question of how the quality of student writing is impacted by the size and structure of the institution. Factors contributing to the poorer quality of writing exhibited by students from a particular school could be a lack of a writing requirement, lack of a writing across the curriculum initiative, class size/ amount and type contact with professors, the structure of the engineering curriculum at those institutions and the emphasis placed on communication skills, and the amount of individual support offered on campus for writing.

Poor writing skills cannot, however, be attributed to these factors alone. Institutional and departmental values—and the role they play in shaping students' values—must also be considered. The *Communication Skills* code and the (*Lack of) Engagement* code both point to engineering students' resistance to written assignments. The *Lack of Engagement* code was applied when a student failed to engage with the learning material, follow directions, or adequately explore the questions posed in the assignment. In responses that received the *Lack of Engagement* code, students often answered questions with one word or very brief answers that were dismissive of the prompt. For example, when asked to pose critical questions about definitions of energy, in the following response the student avoids developing questions and does not thoroughly consider the prompt:

> "I do not have any questions about how the different definitions I read fit together because they are all similar just worded differently." —B14

Cases of poor communication skills and lack of engagement in some assignments point to potential student motivation issues. When students are not properly motivated and encouraged to value writing, they tend to view written work as less useful than quantitative assignments, or even to conclude they are altogether irrelevant to the field of engineering. Engineering professors could motivate career-minded engineering students with the kinds of arguments offered by Harvard English professor James Engell:[14] "[Employers] want flexible, adaptable minds, minds exposed to a broad range of knowledge and trained in rigorous critical thinking. They want students who can think analytically, look at life as a whole, read with interpretive skill, and write decent, well-constructed sentences." Even in the technical field of Engineering, strong language skills are a necessity; to succeed and advance in the professional world, engineers must produce strong proposals and reports, present their work orally and visually, and must have the ability to clearly and eloquently articulate their ideas on a daily basis.

Yet, individual instructors providing such motivation to students in classrooms is not enough. Devaluation of writing and other professional skills persists despite its clear value to industry. According to Engell, there is "an emphasis on majors believed to land a good job, or [the favoring] of law, business, or medical schools...usually justified by an appeal to "utility," to a supposedly clear-sighted appraisal of what the "real" world demands of college graduates...[who assume] that "occupational" courses and majors are superior preparation for adult life."[14] This mythology, maintained in institutions of higher education through disciplinary hierarchies and inequitable funding of research across disciplines, perpetuates the idea that skills like math and writing are dichotomous and unequal, and encourages engineering students to favor technical assignments over written ones.

This dominant mentality is perpetuated within departments when some professors do not require students to do written work within an engineering curriculum, or do not provide them with the guidance and support to develop strong writing skills. At the same time, professors' decisions to place little emphasis on the development of strong writing skills amongst their engineering students is not merely an individual decision, it is reflective of the values and rewards structures of the institutions by which they are employed.

This is clearly illustrated in the case of school D, which implemented Module 1.3, *US and World Energy Needs and Uses*, designed to address the following ABET learning outcomes: *a* (SEM knowledge), *e* (problem solving), *g* (communication), *h* (context), and *j* (contemporary issues). The module is divided into three sections, two of which (1.3.1 and 1.3.3) were completed by the students. It is worth noting that 1.3.2, on the topic of women, poverty, and energy, was omitted entirely. In 1.3.1, students are required to use and develop their information literacy skills by acquiring data comparing the energy usage of the United States to that of other countries worldwide. Students are then asked to think critically about why the United States uses significantly more energy than other developed nations and to articulate their thoughts on the best opportunities for the US to reduce consumption. In Module 1.3.3, students are required to track their energy consumption for one week while trying to live on just 1kW. After analyzing their energy usage and evaluating their energy needs, they are asked to develop and articulate a personal energy reduction plan that would reduce their consumption to 1kW.

The professor at school D, however, adapted and implemented these modules in a reductionist manner. Students were given an assignment in which they were asked to choose between completing 1.3.1 *or* 1.3.3. Additionally, the professor's directions specified that students' responses were not to exceed one page and that their information be presented in the form of a table. Such restrictions meant that the only qualitative information presented by students took the form of terse, one to three sentence answers that either briefly summarized the information already displayed in their tables, or answered questions without critical thought.

The following answer, for example, comes from a student who chose to complete the reduced version of 1.3.3:

> "It states that the United States utilizes approximately 10kW per capita. Over the course of a year I am far above this level." —D1

The reduced assignment structure exempts the student from having to question *why* his/her energy usage is above average, rendering the exercise a purely quantitative comparison rather than an exercise in critical thinking. The professor at school D effectively removed the following ABET learning outcomes from the assignments: *g* (communication), *h* (context), and *j* (contemporary issues), and maintained only the technically oriented outcomes, *a* (SEM knowledge), *e* (problem solving). The case of school D proves that the modules alone are not enough to ensure a truly innovative classroom. They can be reduced/altered by any particular institution, whose institutional culture may produce professors and students who do not value written work. The class size at school D was also likely a critical factor in what the professor felt could be accomplished.

Some students, however, *did* feel that the structure of the assignments—an integration of technical and written work—better prepared them to become engineers than a curriculum comprising only traditional problem sets. In response to Module 2.4: *Hunger, Poverty, and Obesity*, one student wrote the following:

> "When other thermodynamics textbooks focus on thermodynamics and it's relation to biological systems, they forget the relationship between thermodynamics and world food. . .This results in a situation where students are not made aware of these real-world problems. . .By reading about the research done by these scientists and the New York Times article, right now I am more aware of food issues in the USA and around the world. I know how it relates to thermodynamics and how it is an issue that we, as future engineers, can work towards and provide our help in. By doing a series of homework problems related to [thermodynamics], one would be more adept at doing math but still remain in the dark about issues and problems that affect the world and us directly as individuals." —A2

In keeping with this student's remarks, we found that the structure of the assignments contributed to a heightened level of social, environmental, and political awareness that encouraged the development of original thinking skills. The *Original Thought* code was applied when a student developed an original, if elementary, preliminary definition of a term/concept, and did not merely parrot a definition attained from another source. This code occurred most often within the "Engage" section of the assignments, particularly of Module. 1.1, where students were asked to develop their own definitions of the term "energy." The following exemplifies a student response that received the *Original Thought* code:

> "Energy is the action that is needed to get things done. By this I mean that without energy there would be no work (the word work in this form is used very loosely). To move from one point or phase to another requires energy. To get up out of bed in the morning requires a form of energy. To carry on a conversation requires a form of energy. To stop a moving object requires a energy." —B2

In addition to the *Original Thought* code, the final three sentences of this response were also coded as *Personal Experience*. The *Personal Experience* code was applied when a student related a term, concept, or other course material (ie: "energy") to her/his personal life or experience. The two were closely related, as assignments that prompted original thinking often led students to explore and draw upon their own life experiences and observations. This phenomenon further reinforces student A2's assertion that "By doing a series of homework problems related to [thermodynamics], one would be more adept at doing math but still remain in the dark about issues and problems that affect the world and us directly as individuals." The nature of the assignments establishes a crucial link between engineering concepts and the individual, and enables students to understand the implications and impact of engineering in their personal lives. Such understanding is vital for the development of ethically aware and socially conscious engineers. Furthermore, the assignments emphasize and validate the idea that students already possess valuable knowledge. Rote memorization is discouraged in favor of the development of original thinking skills. Such reinforcement teaches students to value and express their own knowledge and ideas, rather than depending upon textbooks and other outside sources to form opinions.

In the later modules completed by students in the study (Module 1.5.1: Power/Knowledge, Module 2.2.1: “Foreign” Oil Independence, Module 2.4: Hunger, Poverty, and Obesity, and Module 4.5: Ethics in Energy Disasters), the original thinking skills cultivated in the earlier modules are evident in student responses that received the *Social/Economic Context* code, the *Global* code, and the *Role of Profit* code. All three codes signified that students were engaging with and thinking critically about important contemporary issues, particularly how engineers should ethically address such issues. The *Social/Economic Context* code was applied when students explored the relationship between the module’s material and contemporary social, economic, environmental, or political issues (for example, pollution, poverty, fracking, etc.). The *Role of Profit* code signified that students explored or acknowledged the role that profit plays in corporations’ decision making processes. Often, students were critical of decisions made by corporations in the interest of profit. As one wrote:

> “Any party’s individual profit should not jeopardize the health, safety, and welfare of the public. But we see that even in the most democratic of nation[s], safety standards are often skewed to profit powerful businesses. These profits or new advancements in any novel field, as in the case of the nuclear industry discussed here [student inserts citation], are used as the ends to justify the means under consequentialist ethics.” —A1

Such astute observations demonstrate that, through the modules, students are encouraged to heavily consider ethics in relation to the implementation of new technology.

Finally, the *Global* code signified that a student recognized the role of competition amongst nations in driving the development of new technology, or recognized technology’s role in the global marketplace. Like the *Social/Economic Context* and *Role of Profit* codes, the appearance of the *Global* code shows that students are engaging with contemporary issues. Furthermore, students are considering the role of technology on a global rather than just domestic level, an important skill as Engineering is not an insular field. The following are examples of how students consider technology on a global scale within the assignments:

> “If the US farm bill currently under place is reversed, then the crops and food produced in developing, third-world countries will actually be sold in their markets without competition from subsidized, cheap US produce and commodities.” —A2

> “This increase may have been a reaction to the recent global recession seen during the same time period.” --C1

> “By reducing oil-related consumption, the United States would become less dependant [sic] on other countries to fulfill its needs, and could instead invest more money in its own national markets.” —A4

The previous three codes—which demonstrate the development of important critical thinking skills—are related to the *Criticality* code. This code was applied when a student critiqued an existing practice or regulatory structure. This code appeared most often in the student work from School A. Students from this institution were particularly likely to raise environmental concerns and consider the impact of technology on the natural world. In the later modules’ assignments, not only do students recognize these critical issues, but actively develop and put forth their own strategies for change. The frequency of the *Criticality* code within such assignments show that , through the modules, engineering students are developing the ability to think critically about contemporary environmental, social, and economic issues, and consider their roles as engineers within this context—a skill that is every bit as valuable as being technically adept. In the following example, a student puts forth her plan to ensure better disaster management after completing an assignment focused on the 2010 BP oil spill:

> "It will be worthwhile for the government to work with scientists and engineers to pass strict laws and regulations around development of robust strategies and systems to deal with design failures. Regulations should mandate industries to prepare better to handle risk events and ensure availability of on-call disaster management teams." --A1

The *Criticality* code appeared most frequently in the work from school A, accounting for 41 of the 43 occurrences. This could potentially be explained by the fact that the modules were developed and first implemented at this institution. Additionally, the structure of School A (a small liberal arts college) fosters an environment in which students are encouraged to think critically and voice their opinions in the classroom. This type of institutional culture could also account for students' willingness to critique existing structures/practices.

5 Summary and Conclusion

With a low response rate and self-selection bias, we cannot draw any sweeping conclusions based on these data about engineering faculty attitudes toward innovation. For our sample, far and away the most important factor influencing the adoption of engineering education innovations is faculty reward structures, particularly tenure and promotion evaluations. A vocal minority in our sample does not feel engineering education innovations are useful, suggesting that there are some strong and well-formed attitudes of opposition to both engineering education research and change in engineering education. Taken together, these results suggest that the most effective routes to supporting change in engineering education would come from a focus on institutional reward systems, along with redoubled efforts in changing hearts and minds of engineering educators who do not value engineering education research. Qualitative analysis of student work suggests that change is limited when only content changes; there needs to be transformation of pedagogy as well. In particular, the critical pedagogies employed in developing the material for the book are relational in nature; to successfully transform thermodynamics classrooms would have required an effort beyond the scope of this grant-funded project seeking explanations for slow diffusion of innovations in engineering education research. At the same time, these failures point to fruitful locations for future change efforts, specifically institutional reward structures and a relational community of practice.

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