Employing Liberative Pedagogies in Engineering Education

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Abstract

Many educators in the humanities and social sciences employ pedagogies of liberation, including feminist and/or critical/radical pedagogies based on the works of bell hooks, Paulo Freire, and others, to engage students in collectively creating a democratic classroom that encourages all voices. This paper motivates the use of these pedagogies in engineering education and presents their application in an engineering thermodynamics course. Implementation areas include relating course material to student experience, facilitating student responsibility for learning and authority in the classroom, incorporating ethics and policy issues, and de-centering western civilization. Assessment approaches are discussed, as well as limitations of liberative pedagogies in an engineering context.

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Introduction

Many educators in the humanities and social sciences employ pedagogies of liberation, including feminist and/or critical/radical pedagogies based on the works of bell hooks, Paulo Freire, and others, to engage students in collectively creating a democratic classroom that encourages all voices. This paper motivates the use of these pedagogies in engineering education and presents their application in an engineering thermodynamics course.

According to hooks (1994), engaged pedagogy holds paramount students' well-being, focusing on the whole student, respecting and caring for a student's entire self, not just her mind. Critical awareness and engagement are central, involving students as active participants in the learning process, as opposed to the consumer model in which information is transmitted one way only. In this new framework, students claim knowledge and expertise of their own in the classroom, enabling teachers to learn as well as students. When students take an active role in their own learning, they have greater responsibility for the process and a deeper engagement with the material. As the stoic philosopher Seneca (1996) wrote, "*non scholae sed vitae discimus;*" we learn, not for the academy, but for our lives.

Most engineering educators have been unaware of these pedagogies, but there is much to be gained in engineering fields by understanding pedagogical perspectives that hold a vision of "education as the practice of freedom (Freire, 1971)." Freire's critiques of education in Brazil have many parallels with critiques of engineering education, from both mainstream and progressive voices. Many of the techniques of liberative pedagogies have some commonalities with other pedagogies better known to engineering educators (e.g., learner-centered or problem-based approaches) – perhaps because good pedagogy has some universal characteristics. However, liberative pedagogies bring new principles and focal points that can push engineering further toward becoming a more diverse and accessible profession, and empower future engineers to find or make a place in the field that resonates with their sense of social justice.

This work is responsive to calls over the past several years for increased use of feminist pedagogies in engineering classrooms and for curricular reform that considers race, class and gender explicitly (Rosser, 1997; Subramaniam et al., 1999). This work is also complementary to the more male-centered literature on engineering education reform, which strives primarily to apply research on learning and cognition (see e.g., Felder et al., 2000). The engaged pedagogy perspective is somewhat different because it holds liberation as a goal, rather than production of effective engineers, a common stated goal for engineering education, and rather than equity, a common stated goal for female-friendly science programs (Rosser, 1997).

There are distinctions among pedagogies termed "feminist" and those termed "critical" or "radical." While there have been feminist critiques of the work of Freire and other progressives (see, e.g., Gore, 1992 or Weiler, 1991) and critiques of feminist pedagogy's sensitivity to race and class issues (see e.g., hooks, 1994), my focus is where these streams converge through dialogue and change rather than where they diverge. Thus I use the term "liberative pedagogies" inclusively, recognizing that no single pedagogy (including and especially mine) will liberate all people.

I share a report of my efforts here in order to raise awareness about these pedagogies among engineers, and to create a dialogue with others who have implemented some of these ideas in their classrooms. I come to this work with humility and an eagerness for continued dialogue, as a queer-identified white woman, committed to struggle against all forms of oppression, but recognizing that there are places where my privileges can get in the way of what I hope my classes can accomplish together.

First, I motivate the use of liberative pedagogies in engineering education, and situate them relative to existing pedagogical and curricular reform efforts. Then I describe my application of liberative techniques in a thermodynamics course at Smith College. This is both to illustrate by example how education as the practice of freedom can manifest itself in an engineering classroom, and to help engineering educators recognize techniques they currently use that may meet the goals of liberative pedagogies. I close with a discussion of the limitations of liberative pedagogies in engineering education, and provide avenues for further exploration.

Critiques of Engineering Education from Three Perspectives

Progressive Critiques

Much of the Brazilian classroom Freire critiques parallels closely the traditional engineering education so many current faculty experienced as students (and continue to practice). In the "banking system" of education, "knowledge is a gift bestowed by those who consider themselves knowledgeable upon those whom they consider to know nothing" (Freire, 1971). Students memorize content narrated by the teacher, and students become receptacles, empty vessels that the instructor fills with his knowledge and perspective. Thus students are passive, merely receiving, filing, and storing these deposits.

Writing at approximately the same time as Freire, the American liberal Charles Reich identified similar problems in the educational system in the United States. His bestseller *The Greening of America* critiques the educational system as mindless obedience training, in which students are taught not to think for themselves, but to repress their desires and interests in other subjects in an effort to repeat certain information and opinions, completing papers and tests according to prescribed standards and in conformity with certain rules. He critiques tests designed to measure students' self- discipline and capacity for obedience – characteristics that ultimately serve what he calls the "Corporate State" – the conglomeration of centralized power in public and private entities that grew out of the New Deal (Reich, 1971).

Traditional engineering education has been so widely understood to be inadequate, it has become cliché: "from professor's notes to student's notes and through the minds of neither." The lecture-only model is still very common in engineering education, and typifies Freire's description of the classroom power differential. Reich's connection between education and the military-industrial complex is nowhere clearer than in the field of engineering, where students graduate in hopes of landing jobs with explicit military and/or industrial applications. Classical cases in engineering ethics (e.g., the Challenger disaster) highlight the problems of expected obedience, when engineers are asked not to think critically but to abdicate responsibility to management (Harris et al., 2000).

These critiques point to the value of a liberal arts education – one that at its core promotes critical thinking, not merely knowledge or awareness of social issues, but the ability to think originally and act in response. This reflective action, or *praxis* in Freire's terminology, is a central outcome that determines the success or failure of liberative pedagogies.

Mainstream Critiques

Critiques of engineering education from within have been raised since at least 1930, with many cyclically repeating themes. Common to reports in the 30s, 40s, 50s, 80s and 90s are calls for strengthening the mathematical basis of engineering, increasing the focus on design and laboratory work, emphasizing communications and social skills, integrating the liberal arts, particularly social sciences, into the curriculum, incorporating good teaching and continued curricular development, and instilling in students an appreciation for life-long learning (NRC, 1995).

Good teaching and curricular development as interpreted by the engineering education community typically means paying attention to student learning styles, and choosing a variety of methods to communicate course material. Felder et al. (2000) provide a typical review of best teaching practices in engineering education from this perspective. Recommendations include having clear instructional objectives, establishing the relevance of the course material, teaching inductively, balancing concrete and abstract information, promoting active learning and cooperative learning, and conveying a sense of concern about students. These are all excellent recommendations that will improve engineering education over its traditional practice, and all are compatible with liberative pedagogies, but more is needed to support students of color and white female students in the educational process.

The current mindset is that improving engineering education in these mainstream ways, without considering gender or race, will help all students, and the rising tide raises all boats. Thus, reforms such as "establishing relevance of course material" are often done only from a white male perspective, and may or may not have relevance for white women and people of color. Rosser (1997) notes that when reforms are implemented after ties to ethnic or women's studies have been severed, the helpful aspects of the reforms for students of color and white women are often lost. Liberative pedagogies focus on the students who are most likely to leave, while mainstream engineering pedagogy resists giving attention to men of color or women, for fear it might detract from the education of white male students. This fear appears to be unfounded, however, as strategies implemented with the intent of attracting more women have been at least as successful for men (Rosser & Kelly, 1994).

Feminist Critiques

Feminist critiques of engineering are usually made in the context of larger critiques of science, math and technology fields. Tobias (1990) identifies problems for women including too narrow a focus, a lack of application, and missing context. Davis and Rosser (1997) review a number of inclusionary pedagogical techniques for teaching science, math, and engineering that draw on ethnic and women's studies methods, including connecting women's life experiences to the subject matter, exploring less military problems and more problems "of social concern," using examples from traditionally feminine fields, describing the global, holistic contexts of problems being solved in class, including women scientists and their work, increasing the focus on communications skills and ethics, encouraging critical thinking to uncover implicit biases in science, and using interdisciplinary, cooperative and interactive approaches to teaching.

Many feminist critiques of science, math, and engineering have focused on science primarily. Critiques of the disciplines of sociobiology (Fausto-Sterling, 1992; Spanier, 1995), biology (Haraway, 1989; Hubbard 1990) and even physics (Curthoys, 1991; Hayles, 1992) are more common than critiques of the discipline and teaching of engineering (though much of what has been said about the other disciplines is indeed relevant). Sally Hacker (1989) offers a feminist critique of engineering education, where she links the technological and the erotic, draws connections among militarism, patriarchy, and engineering, and offers an alternative model to engineering as usual. She provides an insightful analysis of the political conservatism in the profession, as well as an analysis that echoes Reich's work on the culture of the test and the need to subordinate bodily concerns and desires in order to physically endure them.

Critiques of reductionist approaches are of particular interest because they are raised by some feminists and progressives (see e.g., Shiva, 1988), but rarely by mainstream engineering educators, who tend not to question the value of this approach. The Wickenden Report (1930, cited in Hacker, 1989) shows how integral reductionism is in the field of engineering as well as how it is taught:

> Engineering education reflects our national genius for quantity production. Pressed to get a maximum result in a minimum of time, engineering educators have borrowed, half unconsciously, from the management methods of industry. The essence of the scheme consists in first visualizing the process as a whole. Then dividing it into major steps in a logical progression and finally breaking the work down into small units to be done in a definite sequence, under prearranged conditions and with the materials supplied precisely when needed and in the most convenient form, the task sequence to be carried out under close supervision, with continuous inspection and grading of piece parts, and the rewards to be paid in terms of a standard task with quality bonus.

It is this elevation of reductionism that limits the extent to which material from other disciplines can be brought into engineering classrooms. Freire (1971) notes: "[the oppressors] react almost instinctively against any experiment in education which stimulates the critical faculties and is not content with a partial view of reality but always seeks out the ties which link one point to another and one problem to another."

Davis and Rosser (1997) call for less use of reductionism and military applications in the classroom, and call for their replacement with items "of social concern." What they are asking for implicitly is a replacement of old values, which are deeply rooted in patriarchy, colonialism and militarism, with new values, that represent a greater range of concerns, including those of importance to women. I believe that a social-justice orientation, now more than ever, suits the vocation of engineering, offering a replacement set of values for applying mathematical and scientific knowledge to serve humankind and to work creatively for a sustainable future.

Why pedagogies of liberation?

Ignoring oppression doesn't work

While reforms have been implemented from both mainstream and feminist perspectives, progress has been very slow. There are a number of possible explanations that no doubt have some validity: the conservatism of the engineering profession, the organizational structure and reward systems of academic institutions, and an engineering culture that perpetuates bad pedagogy as a rite of passage. Many reforms, taking the "rising tide raises all boats" approach, have simply ignored gender, class and race. Davis and Rosser (1997) note that, when institutions undertake curricular reform, they rarely consider the gender impacts of their efforts, let alone fully integrate curricular reform with strategies to establish gender equity.

Engineers, trained to think reductively, often try to "manage" engineering education through the use of flow charts and quantitative analysis. A by-product of this narrow framework is that engineering educators tend to discount our own privilege, believing that the material we teach is objective, free from social bias. Freire (1971) recognized this phenomenon:

> Many persons, bound to a mechanistic view of reality, do not perceive that the concrete situation of individuals conditions their consciousness of the world, and that in turn this consciousness conditions their attitudes and their ways of dealing with reality. They think that reality can be transformed mechanistically, without posing the person's false consciousness of reality as a problem, or through revolutionary action, developing a consciousness which is less and less false.

Ignorance of race, class, and gender translates into ignorance about classroom power dynamics. Perhaps so little has changed because the suggested modifications have for the most part not been transformative. The relationship between professor and student has not changed; while students have become more active in some classroom environments, the entire curriculum in many situations remains rigid and determined with little if any student input. Engineers miss the social analysis, the realization that people matter, and relationships matter. To truly address issues of diversity in the classroom, instructors must examine our own biases and recognize the roles that privilege and power play in the classroom along lines of gender, race, class, ability, age, sexuality, and professional status.

Diversity programs, which pay explicit attention to men of color and women, often focus on helping underrepresented students assimilate to the dominant engineering culture. While this may be a short-term survival strategy that keeps retention rates up, it dislocates the problem as lying with the students, rather than with the culture that so efficiently excludes them. We will never be wholly successful in raising the numbers of traditionally underrepresented people in engineering by merely teaching them to mimic the thoughts and actions of the majority. "Indeed the interests of the oppressors lie in `changing the consciousness of the oppressed, not the situation which oppresses them'; for the more the oppressed can be led to adapt to that situation, the more easily they can be dominated." (Freire, 1971).

The Future of Engineering Education needs liberative pedagogies

Engineering is changing, though sometimes at an imperceptible pace. One of the most visible changes in recent years has been the adoption of the Engineering Criteria 2000 by the Accreditation Board on Engineering and Technology (ABET, 2002). These criteria explicitly require emphases on ethics and social responsibility, communication skills, team work, engineering fundamentals, design and lab work, a broad education that uses other disciplines to help contextualize engineering work, and an appreciation for lifelong learning.

Many of these changes are driven by industry's demand for these skills (Rugarcia, 2000). As information proliferates and technology changes more and more rapidly, technological development requires engineers to draw on knowledge of multiple scientific and technological disciplines. Thus, industry will favor engineers that can think more independently and take responsibility for their own continued learning. As environmental concerns and the social impacts of technology become higher priorities for society, industry will seek out professionals who can help them meet society's demands. Rugarcia et al. (2000) argue that globalization requires greater cultural sensitivity among the engineering workforce (although it is unclear whether they expect engineers to assist or resist globalization). Diversity has come to be valued to an extent in the workforce for its contribution to creativity. The more perspectives held in a project group, the greater number of alternatives generated, and the more likely that the best, most innovative solution will emerge (Jackson, 1992; McLeod et al., 1996).

ABET's Criteria 2000 recognizes the importance of good communication and ethical decision-making in preparation for the profession, but it stops short of questioning corporate values, a shift that may hold the key for attracting more underrepresented groups to engineering. There is no doubt that critical challenges in engineering in the coming decades will center in the developing world: how will growing populations have access to food and clean water? How will multinational corporations wield power in the two-thirds world, and what will be the governmental and popular response in developing countries? Will engineers design technologies for developing countries that suit local needs and opportunities, or uncritically replicate what has worked in the Western world? Will these engineers be from or trained in the West, or will there be room for local leadership? Will engineers begin to see our work as part of the web of life, considering the total environmental impact of the processes and products we design? Liberative pedagogies are central to the future of engineering, if any meaningful change is to take place.

Education as the practice of freedom seeks to end oppression, not only in the education system, but also in the world at large. Engaged pedagogy teaches people to question authority and challenge oppressive systems in their life's work. Engineering will change as the result of liberative pedagogy, because it will prepare effective professionals who have an added critical awareness of the systems in which they work, as well as the ability and desire to act to change those systems.

Applying Liberative Pedagogies in the Engineering Classroom

Pedagogies of liberation were incorporated in Smith's engineering thermodynamics course. By choosing one of the truly technical courses in the curriculum, I hope to dispel the misconception that liberative pedagogies are not applicable in the highly quantitative environment of engineering core courses.

The Smith College Environment

Smith College is the first women's college to offer engineering in the United States. Samuel Florman (1978) wrote that Smith could never graduate engineers because Smith women came from upper class backgrounds; he has been proven wrong, perhaps in part because of Smith's changing class demographics, and in part because of engineers' changing class demographics (McIlwee and Robinson, 1992).

The environment of support and unlimited possibility for women at Smith draws a broader population of interested students than one might see elsewhere (Mikic and Grasso, 2002). Smith's commitment to non-traditionally aged students and to access and affordability for all women guarantees a diverse population with a broad range of preparation levels.

One size doesn't fit all, and multiple perspectives are needed to meet different women's experiences. The emphasis liberative pedagogies place on learner-centeredness requires that we consider students as individuals and know their interests, and the obstacles they face, to determine which classroom experiences will be most valuable to them (hooks, 1994).

The Course

Engineering 290: Engineering Thermodynamics covers a traditional core curriculum in thermodynamics in one semester, addressing applications in mechanical, chemical, and environmental engineering. After establishing a base of skills and knowledge (equations of state and properties of pure substances; the first law; the second law; and the fundamental property relations), students apply these principles to characterize different kinds of engineering systems, including engine and power cycles, phase and chemical reaction equilibria, and solution thermodynamics. The course objectives state that students develop:

- An intuitive understanding of common thermodynamic processes in engineering practice
- The ability to derive mathematical relationships in thermodynamics and apply them to engineering systems
- The ability to solve engineering problems in thermodynamics
- The ability to model a thermodynamic process using design software
- An appreciation for the philosophical and cultural significance of the 2nd law of thermodynamics
- Knowledge of the historical context in which thermodynamics was developed as a field in western science, and of non-Western thermodynamic technologies
- The ability to relate thermodynamic principles to everyday life
- The ability to think critically about thermodynamics and engineering ethics

The course was taught in both the spring and fall semesters of 2002. There were 16 students in the spring semester: 12 white students, 2 Asian-American students, and two international students, from Nepal and Nigeria. In the fall semester, there were 10 students, all from the United States: 7 white students, 2 students of African descent, and one biracial student of African and Asian descent. All students are women.

As the course developed, some elements were added in the fall semester, and others were given greater emphasis. Adjustments and additions were made with the help of one of the students over the summer of 2002, based on student input as well as ideas from liberative pedagogies. This is a continuing process of transforming a traditional thermodynamics course into one that effectively employs engaged pedagogy.

The discussion successively presents each type of reform suggested by liberative pedagogies that I have implemented in this course. As different course elements and student work are brought forth, I note the students' rankings of the material from two different assessment tools. The first measure (Table 1) is student answers to the question "what three things did you like most about this course?" (and "what three things would you most like to change about this course?"). The second measure is student responses to a set of items in which they ranked course elements (Table 2) and assignments (Table 3) on a 1-5 scale, with 1 being low and 5 being high.

Connecting experience to life

Common among mainstream, feminist, and critical pedagogies is the principle of relating course material to student experience. Beginning with something students know helps to motivate learning and imbue a sense of confidence. Of course, the challenge is to find an application that resonates with students and is not so complex as to intimidate them. Too often the practical knowledge drawn upon is some knowledge assumed to be universal that really isn't (e.g., student familiarity with car engines).

While it may be possible to find systems that might draw on more universal experience, it is increasingly important in a diverse classroom to offer a variety of examples. Faced with a narrow, predefined set of examples heavily used in thermodynamic textbooks, I chose home refrigeration systems as a complement to car examples. While they carry their own gender baggage, they serve as an entry point for many students, and provide a bridge from everyday life to engineering applications. Over time, examples can be developed for alternative energy technologies, and for intermediate technologies that require less intensive capital investment and energy use. When multiple examples are presented, without the expectation that any one system is familiar, it becomes possible to strike a balance between what students know and what will expand their horizons.

The textbook we selected for use in the second offering of the course (Çengel and Boles, 2002) has a wide range of real-world examples. However, when experience is brought into a course uncritically, it can simply repackage old biases. A special section on food, diet, and exercise accurately addresses the problem of being overweight and offers a scientific analysis of dieting, but it unfortunately fails to address key issues related to body image and eating disorders. Many homework problems are calorie-counting exercises involving fast food and diet sodas (or alcohol and treadmills!). Nevertheless, the concrete examples provide a springboard for relevant conversation about students' lives, so that we can bring in concerns relevant to women.

Betraying engineering's military and nationalist biases, Çengel and Boles (2002) offer the following discussion of entropy:

> Having a disorganized (high-entropy) *army* is like having no army at all. It is no coincidence that the command centers of any armed forces are among the primary targets during a war. One army that consists of ten divisions is ten times more powerful than ten armies each consisting of a single division. Likewise, one country that consists of ten states is more powerful than ten countries, each consisting of a single state. The *United States* would not be such a powerful country if there were fifty independent countries in its place instead of a single country with fifty states. [authors' emphases]

This passage clearly reminds us, "no education is politically neutral" (hooks, 1994). It underscores the importance of teaching students to think critically and challenge ideas, even those presented in an "authoritative" engineering textbook. As a visiting professor from Sweden shared in class, the authors fail to note that low-entropy (highly organized) systems are more vulnerable than high-entropy systems (thus in the military analogy, the US would withstand a great deal more damage from a bombing campaign than the same campaign might accomplish in a country such as Iraq). We problematized the "order – good, disorder-bad" assumption, offered a more Foucauldian analysis of power, and told a more complete story about entropy.

As an alternative or complement to such real-world examples, common experience can be established in class in the form of a laboratory or in-class demonstration. For example, we took a field trip to tour the campus physical plant allowing students to learn how their own dormitories are heated. We conducted a demonstration of a steam-powered pump in class by boiling water in a corked filter flask. Students were asked to make predictions about what would happen and we discussed the phenomenon after the demonstration. Later in the semester some students created their own demonstrations and conducted them before the class. In the second manifestation of the class, additional demonstrations included two developed by students from the first class to illustrate the first law and how heat engines work.

Students as authorities in the classroom

Engaged pedagogy respects students in the classroom as authorities in their own right. The key, hooks (1994) says, is to help students "come into voice," to be able to speak authoritatively in class. Creating a community of scholars in the classroom is the goal, and if students and instructor can each bring knowledge and experience to share, it demonstrates that students have valuable contributions to make, and that everyone deserves to be heard.

Students find themselves in a teaching role frequently in our classroom. They often explain problems they have done individually or in teams. Occasionally they teach course material. For example, we divided the class into groups, and each was responsible for teaching one section of the chapter on heat effects. Two groups made use of technology in instructing students, and one group used an in-class activity, in which groups of two were asked to choose materials to effectively insulate ice to prevent it from melting. While each group deeply understood the segment it was teaching, their difficulties in communicating new concepts to their peers sometimes limited what the rest of the class was able to gain from the exercise. It ranked 3.3 on a scale of 1-5, with 3.4 as the average for all assigned work.

Students were also asked to assume a teaching role as part of a group project to develop supplemental materials on particular course topics – some made interactive web sites, some made videos, some did in-class interactive demonstrations to drive home course material. 10 out of 16 students mentioned the project as one of the three things they liked most about the class. The project ranked 3.9 on a scale of 1-5, with 3.4 as the average for all assigned work. Each group covered a different segment of course material, and course presentations in the last week of the semester served as an excellent peer-centered review for the final exam.

Combining the goals of helping students develop authority and relating course material to their experience, students complete open-ended assignments to "relate thermodynamics to life." The goal is for students to reflect on the course and what it means to them personally and/or professionally. Some took the opportunity to explore topics that interested them – microprocessors, turbochargers, electric eels, energy policy in the developing world. Others found thermodynamics in pockets of everyday life – ice cream, playing the French horn, road trips, beer, blow dryers, hiking clothes, home energy efficiency, and exercise (from rowing crew to stepping with an African-American fraternity). Others sought to build interdisciplinary connections with other courses, reflecting philosophically on the arrow of time, or spiritually on the origins of the universe.

One student reflected on thermodynamics and poetry, and included some of what she wrote for me in the preface of her portfolio for her poetry class. "The first law of thermodynamics states that energy within the Universe is conserved. This means that whatever effort is put forth to create a poem will be recovered eventually. This is regained when the poet feels elation either from the delight he [sic] feels from his art, or in the delight that others take from his work…." Another student calculated how "powerful" she was while running. She determined that burning 936 Cal/hr running was equivalent to 1088 Watts of power. "While running I am like 18 light bulbs. How's that for being bright?"

Students were free to pursue their own interests, in order to integrate parts of themselves (poetry, creative writing, spirituality, sport, favorite foods, etc.) with the course material. In its first incarnation, 4 of 16 students put it in their top three things they liked about the class. It ranked 3.4 out of 5, with 3.4 as the average for all assigned work.

Creating a community of scholars

We tried a number of things in the first rendition of the course to create a democratic community of scholars in which we were learning and teaching together. First, we deliberately switched the assigned room so we could arrange the class in a circle, where we all could see each other and relate to one another. We made this change mid-course because our originally assigned room had fixed desks in rows, resulting in students relating only to me, competing with each other for my approval and attention (so that some students felt excluded), and not taking responsibility for their own learning. This change was well received by students, because we talked explicitly about it, students understood why we were doing it, and they felt the difference right away. 5 of 16 students mentioned their appreciation for the room change, the quality of discussion, or the class dynamics as one of the three things they liked about the class in their final survey. The room change received a 3.75 rating on a scale of 1-5, where 3.25 was the average rating of other class elements.

The emphasis on collaboration extended to one of the two hourly exams offered in the course. Pairs of students worked together on the 24-hour take home. 5 of 16 students mentioned the group exam in their top three things they liked about the class. The group exam ranked 3.9 compared to 2.8 for the individual exam, with 3.4 as the average for all assigned work. One student wrote on her course evaluation: "Fantastic idea – [my partner] and I both felt we understood the material by teaching one another." Another said, "[The] group exam really solidified my conceptual knowledge/understanding."

Taking Responsibility for one's own learning

Another key goal of liberative (and many other) pedagogies is for students to take charge of their own learning. This transformation began in my class when we switched class structure, but initial student response was mixed, as some students invested in traditional frameworks resisted this new responsibility and the increased work it entails.

We made a number of decisions as a class, giving students more ownership of the course. We had meta-cognitive discussions, in which students reflected on what was and was not working for them, given their individual learning styles. We discussed the importance of learning to do derivations; motivating that central piece of thermodynamics for students was extremely helpful in raising their morale and developing a positive attitude toward that aspect of the course.

Students wrote summaries of textbook chapters toward the end of the course, in which they were asked to reflect on what they understood well and what questions they still had about the material (these received an average rating of 3.4 out of 5). Similarly, I used ungraded concept tests as a way for students to monitor their own progress in learning material (which received a 3.3 out of 5, with 3.4 as the average). The mid-course minute paper and problem set assessment survey tool each included questions that prompted students to reflect on what they could do to improve their experience of the course.

Students were most dissatisfied with the ultra-conventional textbook used in the first offering of the course (students gave it a 2.2 out of 5, with 3.25 as the average for all course elements) – 13 of 16 students mentioned it as one of the 3 things they would change about the course. Therefore, students had the opportunity at the end of the course to review current thermodynamics textbooks and provide feedback to me for selecting a book for the next class.

When an instructor encourages students to take responsibility for their own learning, s/he communicates a confidence in students' ability to manage their own learning and to be a success. In discussing oppressors who come to be in solidarity with the oppressed, Freire (1971) notes that they "almost always bring with them the marks of their origin: their prejudices and their deformations, which include a lack of confidence in the people's ability to think, to want, and to know." Ageism and sexism, racism and classism can contribute to the patronization that occurs in engineering where we presume to know what's best for our students. There is a prevailing belief in engineering that some students are not "cut out" for it – I have been trying to figure out what this means ever since someone first said it to me. Sometimes educators are using proxies to make that judgment – a student's gender, or race, or sexual orientation – her self-confidence, his lack of adherence to some expected dress code. As educators, it is not for us to be the gatekeepers. We cannot believe that we and only we know anything; we must believe in our students' capacity to be good learners and amazing engineers.

Ethics, Policy, and Integrity

Integrating issues of ethics and policy in engineering education is central to the goals of liberative pedagogies. Students must understand what it means to be a professional engineer, and to know the impact their work will have on society and the world. The weight of responsibility is often frightening to students, but it is also an opportunity for them to make positive changes where they are able. In my first teaching of the course, these issues emerged primarily in the "relate thermo to life" assignments, and in two videos we watched and discussed on energy in society. While these were good conversation starters, there is a need to deepen the analysis.

We did talk some in class about the textbook we used (Smith and Van Ness, 2000) and the kinds of things included as examples, as well as what could have been included. Alternative energy, energy systems for developing countries, and environmental applications of thermodynamic theory were not included to the extent desired (although a unit on fuel cells toward the end of the book was a nice add-on). A willingness to critique the textbook (and supplement it where deficient) is crucial to engineering education, because we typically have few choices and ultimately select one book from one perspective for student learning.

In the second manifestation of the course, students are assigned ethics problems to reflect on over the course of the semester, and I facilitate a dialogue among students. The goal of these assignments is for students to practice seeing ethical problems from a number of perspectives, and to practice talking issues through with colleagues. In the second rendition of the course there were four ethics case studies (drawn from Harris et al., 2000) that dealt with thermodynamics (on a variety of topics including environment, safety, conflict of interest, honesty, etc.). These case studies are discussed via student reflections posted to a Blackboard bulletin board, and in class. Harris et al. (2000) provide a particularly effective resource for teaching ethics because it contains both realistic (often real) case studies and the conceptual frameworks students need to structure their reflections.

There is a big "elephant in the living room" when we teach engineering, which is that student employment opportunities typically center around military defense, or around multinational corporations, many of whom are vilified by some of our same students for their colonialist monopolies around the globe. Helping students discover what their values are, and how to live them out, is a cornerstone of education. While liberative pedagogies come from a progressive orientation, they are not meant to result in indoctrination of students; on the contrary, learning to think critically allows students to make up their own minds. Conventional engineering education, by not questioning any application of technology, creates a values vacuum in which everything is sanctioned, or nothing, so that students have no basis for decision-making.

hooks (1994) cites a passage from King's April 4, 1967 speech as a call for individual transformation among instructors using engaged pedagogy, but the words carry an additional message highly relevant for engineering educators. Speaking about the global economy and Vietnam, King noted that the United States was on the "wrong side of a world revolution":

> Increasingly...this is the role our nation has taken--by refusing to give up the privileges and the pleasures that come from the immense profits of overseas investment.... When machines and computers, profit motives and

> property rights are considered more important than people, the giant triplets of racism, materialism, and militarism are incapable of being conquered (King, 1967).

We have to realize that militarism and materialism are the very drivers of engineering, and are the source of many of our students' future employment. To discuss this meaningfully with students requires ethical decision-making skills and skills in social and policy analysis. While we can hope that our students pick some of these up in other courses, it is still incumbent upon us to help students make the connections between those skills and their usefulness in their careers and personal lives. This also requires us to examine our own research, our funding sources, and the social ends to which we commit our life's work.

Race and Class in the Engineering Classroom

As globalization becomes increasingly central to American industry, engineers must consider issues of race, class, and culture, bringing us precisely to the place bell hooks (1994) is writing from in her work – that is, how to teach students an awareness of race, class, and gender, and a critical perspective from which to analyze events personal and political. Many will respond that these discussions belong outside of engineering classes. I believe it is a cop-out to say that we as engineering professors are not capable of conducting discussions on racism and classism and therefore we are exempt from doing so. To continue to ignore race and class is to send a clear message to our students that this is what is expected of them as well. We need to create avenues whereby students can make the connections between what they learn about race, class and gender, and what goes on in their major and profession. This is a lifeline for students of color and white women, who will need these tools to understand and counter racism and sexism in the organizations in which they work.

In thermodynamics, issues of energy supply and availability can serve as gateways for discussions of class issues. Economic disparities are a central issue in meeting the energy needs of the developing world. More mundane class issues that are nonetheless visceral for many students arise in considering the costs of engineering textbooks. I could not recommend students purchase both class texts due to cost. I placed all course materials on reserve in the library so that students would not necessarily have to purchase both books. While it was not practical to permit students to buy a previous edition of the textbook (problems at the back of each chapter change, etc.), I did encourage them to buy an earlier, cheaper edition of the ethics book.

De-centering Western Civilization

An obvious problem in teaching thermodynamics rests in the fact that the traditional body of knowledge is wholly western-centered, with predominantly white male upper class heroes. It is possible with a little digging in the history of science literature to turn up countercurrents in this stream.

For example Maria the Jewess was a non-western thermodynamicist who lived in Africa in the first century CE, and developed the still (among other things), which makes a great case study for teaching phase equilibrium (Taylor, 1949). It is important to both recognize the contributions of non-white and non-male contributors to the field and be clear with students about the fact that mainstream books on thermodynamics and even the history of thermodynamics have left these contributors out. Such contributors may have been relatively rare in the past for specific historical social and political reasons that need to be understood as well.

To date I have gathered resources on inventions in non-Western civilizations that deal with thermodynamic principles, including under-floor heating in China, human- and water-powered fans in China, Egyptian oil lamps, Muslim commercialization of oil lamps, and the development of water wheels and wind mills for power generation in the Muslim world (James and Thorpe, 1994; Al-Hassan and Hill, 1986). A number of women's inventions include the double boiler (*bain marie*), pyrotechnic night signals, a number of kitchen process improvements from potato boilers to stoves (MacDonald, 1992), and contributions to power generation and engine development (Stanley, 1993). In the future, I hope to incorporate examples from the ethnoscience literature, including examples of technological enterprise in the developing world.

My original lecture discussing perpetual motion machines presented a drawing by Villard de Honnecourt, a European mason and inventor living in the 13th century; this drawing was represented in the book I drew from (von Baeyer, 1999) as one of the earliest. I learned in reading about Islamic technology (Al-Hassan and Hill, 1986) that extraordinarily similar machines were found in Arabic manuscripts from the 9th-12th century. Thus, my lecture has been altered to reflect both Honnecourt's drawing and the earlier ones from the Arabic manuscript, which provide for an interesting discussion.

As I present these developments from non-Western and non-male inventors, I recognize the concerns about appropriation. I may not fully understand the cultural contexts out of which these inventions grew. Ongoing dialogue is important, especially with social scientists and historians of science. Ultimately, these examples need to be fully integrated into the textbook, problem sets, and other course elements, so that students can analyze and examine these technologies, rather than just hear mention of them.

Additionally, to coordinate with Smith College's Otelia Cromwell Day (a day of education around race issues, named for the first African-American student at Smith), students were asked to write a short paragraph profiling a woman in thermodynamics who is of a different racial/ethnic background than her own. Interestingly, students of African descent reported to me that they easily found women thermodynamicists from their own background, but had trouble finding ones from a different racial/ethnic heritage. The key lesson of the assignment is to impress upon students the value of making intercultural and interracial connections with their peers – in this case, in order to network and identify the individuals they seek. It also assists course development, so that in the future, work of women in thermodynamics from a broad range of backgrounds can be incorporated.

Language is important in this de-centering work, and throughout the teaching process (see hooks, 1994 for a full discussion of language issues). Choosing reading material with even superficially unbiased language (without "the engineer… he") is difficult in engineering, to say nothing of deeper biases in how we express our understanding of engineering phenomena. Where biases are apparent, I find it helpful to acknowledge it in front of the class. This affirms students who noticed they were excluded, and helps those privileged by the language choices to become more sensitive to language issues.

Relativism and uncertainty

An important part of affirming diverse experiences in the classroom that can be a stumbling block for engineers is the possibility of affirming multiple truths. hooks (1994) suggests that multiple approaches to a subject would naturally follow from a multicultural setting. Although one would expect a truly learner-centered environment to produce just this effect, most engineers eschew relativism as if defending a core moral value.

Thermodynamics provides wonderful examples that counter the notion of science as objectivity. The second law has no direct proof, only centuries of scientists and engineers trying to disprove it, pursuing elusive perpetual motion machines. The proof of the second law is statistical – you can imagine a process in which ink dispersed in a glass of water coalesces back into a droplet – but the probability of it happening is infinitesimally small.

This highlights the importance of uncertainty in engineering curricula. Morgan and Henrion (1990) enumerate the types of uncertainty characterization and analysis in engineering. The authors advocate for considering not only the familiar uncertainty in empirical quantities, but also uncertainty resulting from assumptions and approximations, from incomplete information, from linguistic imprecision, from disagreement among sources or experts, and even uncertainty about uncertainty itself. To consider uncertainty formally is to recognize with humility that there are limits to what we know.

Nevertheless, objectivity remains a necessary -- even desirable -- goal in many aspects of engineering. Competence is an ethical duty; the bridge must stand up, ensuring the safety of the public. Some things that are "only social constructs" are useful in that they result in reliable systems. The key is to know when there is a right answer that must be found (within prescribed bounds of uncertainty), and when it is necessary to challenge convention and assumptions. Liberative pedagogies' focus on critical thinking produces this kind of discernment in students.

Respect for students in the learning process: normalizing mistakes

I work very hard to foster student attempts at problem solving and other skills, to build their confidence and enable them to move forward from points where they get stuck and do not know how to proceed. I strive to create an environment in which it is ok to be wrong, in order to learn from our mistakes. This means relinquishing some of my own power by admitting when I don't know something. Many found it helpful to hear other students' perspectives on how to approach a problem, but others very clearly expressed a desire for me to present a single correct way to approach a problem, along with the answer.

A great deal of class time is devoted to problem solving, undertaken mainly by students. Sometimes we work in pairs or groups, sometimes individually. I ask for volunteers to try problems on the board. I never force people to the board, but encourage people who are lost or stuck to come forward so we can all learn together. Eventually, every student came to the board. Two students cited this element of the course as one of their three favorite things. In the words of one student: "I hated being forced to go to board at first, but you made it very comfortable by letting us know it was ok to mess up." I think it tells us something about the power dynamics of education-as-usual that the student felt forced initially, even though I only asked for volunteers. Students gave this a 3.125 rating, with 3.25 as the average for all course elements.

History and Philosophy of Science: The Process of Discovery

The messiness of the development of the first and second laws illustrates not only the lack of an absolute, but also the acceptability (even desirability) of making mistakes as part of the learning process. Sadi Carnot contributed to the theory of the second law while believing wholeheartedly that heat was a material substance called caloric. Julius Mayer, a physician not a physicist, discovered the first law on a boat in Indonesia, following a line of logic that stemmed from his work in blood letting (the standard of care in that day) and the animal theory of heat (von Baeyer, 1999). Assigning first papers (Count Rumford's cannon boring experiments and Joule's mixing experiments) helped students see how science is done, and that one can still make a contribution without having everything exactly right.

The history and philosophy of science pieces woven through the class were well received by some students, with 4 of 16 students mentioning it as one of their three favorite things about the course. However, others did not like it – one student mentioned it as one of the three things to change about the course next time. Overall, the history pieces ranked 3.1 and the philosophy pieces 3.2, with 3.25 as the average of all course elements.

In the second rendition of the course, more time is built in for student reflection on how studying the history and philosophical impact of thermodynamics aids in their learning, not only of the course material, but also of the process of discovery and the role of creativity and productive errors in professional life.

Assessment

Because the goals of engaged pedagogy are different, assessment should similarly be different. In Freire's terms, the proof is in the praxis. Successful pedagogies of liberation will result in student reflective action. How students choose to live their lives is the ultimate evidence of effective teaching methods. Some measures that can be taken on the time scale needed for conventional education include assessing student abilities to think critically, and assessing how well students have applied course material to their lives. Neither of these is as quantitatively assessable as knowledge measured by written exams or multiple choice testing, but in some ways the qualitative information is more complete, especially when used in consort with more conventional knowledge or skills testing. Other key measures, especially for women in engineering, are confidence levels and student empowerment. Both can be measured by adapting tests from psychology, but finding a fair comparison group for benchmarking may be difficult.

Assessment of students involves a greater emphasis on participation in this framework, and a more flexible grading system due to the wider variety of assignment types. Grading can be somewhat more subjective, but the use of rubrics can aid students in understanding what is expected. Smith engineering is currently experimenting with student portfolios as an effective tool to enhance student learning and meta-cognitive reflection. Such a framework lends itself to liberative pedagogies, so that student-defined goals as well as course-specific goals can be identified and their achievement measured over time.

In the first manifestation of the course, I used two hourly exams and a final, as well as weekly graded problem sets to assess student mastery of technical material. I allowed students to collaborate on problem sets, with individual write-ups; I also allowed paired collaboration on one of the hourly exams. In the second manifestation of the course, problems are not graded in order to make them more purely a learning exercise and not an assessment tool (students get credit for solidly attempting problems, to ensure they do their homework). I give fairly traditional biweekly quizzes and a final exam, which are focused on measuring knowledge and problem-solving skills related to the technical material in the course. An open-ended modeling project measures student ability to translate the fundamental principles of thermodynamics to engineering applications, using the ASPEN chemical process simulator.

The ethics assignments are graded using a rubric that evaluates student writing quality, critical thinking and analytical skills, ability to consider more than one ethical perspective, structured argumentation, and creativity. The assignments relating thermodynamics to everyday life are also evaluated according to a rubric, in which the quality of the writing, technical explanation, reflective thought, and creativity are evaluated.

A critical issue in engineering education is grading. Traditionally, students are graded on a curve, relative to each other. This often sets up a competitive environment antithetical to the goals of engaged pedagogy. If students are expected to learn cooperatively and create a positive class dynamic, the assessment system needs to reflect these expectations. More carefully designed tests that truly focus on the material and skills that were taught can significantly change the shape of the distribution of student grades. Moreover, these teaching methods can result in less dependence on tests as the sole measure of student learning, utilizing a broader set of tools to capture what students know.

I provide continual opportunities for student feedback. An introductory survey assesses incoming student knowledge and class expectations. An fourthweek survey assesses time management issues and areas of challenge for students. A midterm minute paper collects general feedback on how the course is going in time to make midcourse corrections. A final survey assesses student confidence levels with course material and collects feedback on instructor quality, assignments, and other items. In addition, an anonymous feedback form is placed on the course website, and students frequently offer constructive course feedback directly to me.

Conclusion

Limitations and Critiques of Liberative Pedagogies

Time is the single largest barrier to implementing liberative pedagogies in engineering education (and likely in any field). It takes time and work to develop the new assignments and new lecture material that I have described in this paper. It takes more class time for students to teach each other how to do problems, for discussions, demonstrations, field trips, and other events that help students connect with course material. I changed the scheduling of thermodynamics from 3 to 4 hours a week in order to allow extra time for student learning in this way. Even with this added time, I have taken out time spent going over material in the book, holding students more responsible for doing and understanding the reading. Students often resist liberative pedagogies precisely because they are being asked to take responsibility for their own learning, which requires additional work on their part.

Despite all this extra work, it has been said that liberative pedagogies turn classes into group therapy (hooks, 1994). While I suspect engineering classes are less likely to experience this critique due to the course content, a related critique is likely to emerge related to how "soft" the course is. Its ideal opposite, "rigor," is code for rigidity, discipline, or as in Hacker's (1989) critique, subordination of bodily needs and desires to the power of the test.

There is a common misperception that discussing ethics or the social implications of technology takes away from quantitative instruction. We must remain steadfast in challenging the elevation of reductionism to the exclusion of integrated and interdisciplinary thought, and remind detractors that ABET and many engineering education critiques call for consideration of exactly these issues. We must also ensure that students develop excellent quantitative skills.

A second criticism of hooks's pedagogy is that the teacher loses control of the classroom when s/he adopts a classroom style (more) grounded in mutuality and respect. I have found the exact opposite to be the case – that students were "out of control" when I used a top-down teaching style because they weren't taking responsibility for their own learning or for the class dynamic. At its core, this argument is about power. Instructors have it, students don't, and if the goal is to empower students, instructors need to cease clinging to power for its own sake.

Rugarcia et al. (2000), writing to a mainstream engineering education audience, note this same concern about active learning and learner-centered education in general. Their response is simply that directing student-centered classes is an ability that requires training and time. This may be true in the sense that alternative leadership styles differ from traditional top-down hierarchies, but remain a conduit for authority. However, the authors minimize or overlook the fact that there is a very real sharing of power when these teaching styles are adopted.

The implementation of liberative pedagogies in engineering education begs the question: If our students learn to notice oppressive structures and are critical of them, can they succeed as engineers? Or is ignorance the ticket to success? The reality is that students must be able to function in both worlds – to be top-rate engineers yet to be critical of the systems they build, and of the systems in which they work. We need to be honest with students that there is a cost associated with standing against injustice, potentially including career setbacks.

Rosser (1997) discusses the transition from single-sex to coeducational environments for scientists graduating from women's colleges and attending coed graduate programs. Specific recommendations at the undergraduate level include providing students with summer experiences in conventional environments, inviting alumnae back to share their experiences, exposing students to as much engineering as possible, especially hands-on research experiences, and frank discussions with students to help them identify what aspects of the undergraduate environment they find most helpful to them, and to share with them how the environment changes in graduate school. Analogous suggestions might be made for students familiar with engaged pedagogy transitioning to traditional education environments.

A key logistical limitation to employing these pedagogies is class size. In a small liberal arts college, we have the luxury of small class sizes so that these techniques work extremely well. But in larger schools where engineering class sizes rise above 15 or 20 it becomes more difficult to employ these techniques (but not impossible – see, e.g., McKeachie, 1999, for suggestions for large classes). In some schools advocacy is needed to provide the same faculty-student ratio in engineering that exists in other departments. Changing the structure of engineering courses to create small group sections, or some similar arrangement, may help foster collaboration and discussion as well. This may require some physical changes as well – desks bolted to classroom floors in hierarchical rows present a significant barrier to some of these techniques.

Finally, training instructors to carry out this wide range of activities is a challenge. I bring an unusual background to my teaching, including feminist and other progressive activism, a broad undergraduate education in a challenging liberal arts environment, and an interdisciplinary doctorate in engineering and public policy, including training and teaching in ethics. Typically engineering professors are not skilled in facilitating discussions, providing feedback on writing assignments, or developing assignments that teach social analysis. Perhaps some of these skills can be developed through campus teaching and learning centers. More specific training, for example, in ethics, might be available through nationally funded workshops, but it requires a time commitment and institutional prioritization so that faculty members are rewarded for their efforts. This is a short term problem, however, as eventually more engineers will emerge with an integrated perspective and sufficient grounding in the liberal arts.

Further work

This paper presents an initial foray into the details involved in reforming a course to meet the goals of liberative pedagogies. Continuing and deepening the relationships with women's studies, ethnic studies, and history of science and technology will produce better integration of material in the course. At the same time, additional work in ethnic and women's studies is needed to flesh out the critiques of engineering as a field, its messages and metaphors.

How can resources developed for specific courses be shared and implemented in similar courses on other campuses? How can techniques developed for small courses at a small liberal arts college for women be implemented in coeducational environments, in larger class settings, or with other instructors less familiar with the material? Can the work be extended to consider other forms of difference in the classroom? Class issues in engineering are particularly intriguing: can engineering continue as an accessible profession to people from a variety of economic backgrounds, or is that an historical artifact of post-World War II initiatives?

Developing an assessment strategy that is true to the pedagogical methods described here is a great challenge. It is important not only to assess what students are learning, but also how they are translating that knowledge into reflective action.

It is my hope that other faculty members interested in making these kinds of transformations in their own courses will find this discussion helpful, and continue the dialogue by sharing their findings. While most faculty are not in a position to completely redesign our courses; hopefully, rather than throwing up our hands at such a daunting task, we can make incremental changes, and, by sharing our results, move engineering education forward.

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Table 1: Final survey question results spring 2002 (n=16, only responses with more than one student responding reported)

What three things did you like most about this course?		What three things would you most like to change about this course?	
Answer	Number	Answer	Number
Group Project	10	Textbook	13
Group Test	5	More conceptual emphasis	7
Accessibility of Professor	5	More applications/examples/demos	6
Change to Circle/Class Dynamics	5	Concept tests	2
Thermodynamics to Life	4	Final weighted too high	2
History of Science components	4	Professor not organized	2
No laboratory	3	Bad time of day	2
Video	2	More class time	2
Philosophy of 2^{nd} law	2		
Professor improved	2		
In-class problem-solving	2		

Table 2: Student ratings of course elements (instructional materials and delivery), spring 2002 (n=16)			
Item	median	mean	stdev
Textbook (Smith and van Ness, 2001)	2	2.2	0.66
Supplemental Reading (1^{st} papers by Joule and Count Rumford, Environmental applications of Fugacity paper, heat transfer reading)	3	2.9	0.68
Course material (incorporated into lectures) on history of thermo (Rumford, Joule, Mayer, Carnot, etc.):	3	3.1	1.00
Course material (incorporated into lectures) on philosophical implications of 2^{nd} Law:	3	3.2	0.98
Other use of powerpoint to teach course material	3.25	3.2	1.09
Use of **student** board work to teach course material	3	3.1	1.09
Use of **instructor** board work to teach course material	3.25	3.5	0.88
Use of Excel in class to teach course material:	3	3.1	0.85
Video ("The Man who loved Machines"):	4	3.9	1.03
Steam Engine Demonstration	4	3.9	0.72
Room change/move to sitting in a circle	4	3.8	1.13
Professor's Office Hours (also state # of times you went)	4	4.0	0.97
TA's Office Hours (also state # of times you went)	2.5	2.6	1.44

Table 3: Student ratings of course assignments, spring 2002 (n=16)			
Item	median	mean	stdev
Problem Sets	3.5	3.4	0.96
Chapter Summaries	4	3.4	1.31
Relating Thermo to everyday Life	3	3.4	0.96
Group Project	4	3.9	0.93
Student Instruction on material in chapter 4	3	3.3	0.95
Quality of Exams (overall)	3	3.3	0.70
Individual Exam	2.5	2.8	0.98
Group Exam	4	3.9	0.72
In-class Concept Tests	3.75	3.3	1.19