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From Persistence to Resistance: Pedagogies of Liberation for Inclusive Science and Engineering

Donna Riley and Lionel Claris

Smith College, Massachusetts, USA

ABSTRACT
This paper describes liberative pedagogies and their implementation in a women's college engineering classroom. A variety of assessment techniques employed in the first three years of a five-year study on liberative pedagogies in engineering reveal a clear dynamic of resistance. Assessment data are interpreted drawing on Foucault's theory of resistance, developmental theories of critical thinking and reflective judgment, and the literature on liberative pedagogies itself, in order to better understand the causes and focal elements of resistance, and in order to evaluate the role of resistance in the learning process. How can we apply ideas from feminist and critical pedagogies in science and engineering classrooms? How do these pedagogies of liberation challenge students' epistemological assumptions, that is how they know what they know, and epistemologies of science? How do we make sense of student resistance in the classroom, and how can we tap this resistance as a positive learning tool? If the role of women (and men) in engineering changes from persister to resister, even a group small in number may have a large and long-lasting impact on engineering education and practice.

KEYWORDS
Liberative pedagogies; critical thinking; reflective judgment; power relations; engineering; thermodynamics; critical pedagogy; feminist pedagogy

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INTRODUCTION AND MOTIVATION

For decades, a major focus of research on women and gender in engineering has been the twin issues of overall underrepresentation and persistence (recruitment and retention) of women in the field through educational and career stages modeled as a 'leaky pipeline'. Numerous studies in the United States have documented women persisting at lower rates than men in science, math, engineering, and technology (SMET) fields (e.g., Berryman 1983; Felder et al. 1995; Seymour and Hewitt 1997; Xie 1995; NAS 2007). Recently some studies have suggested that there may be less gender difference in persistence among engineering undergraduates than previously thought (Wyer 2003; Ohland et al. 2008). The problem of persistence, however, is merely a symptom of a larger problem of underlying sexism and other structures of power in the fields of science and engineering.

Work addressing women's under-representation in engineering has often focused on extra-curricular programs that encourage persistence through mentoring and other kinds of support. However, Lewis (2003), in writing about minorities in engineering, points out that extra-curricular programs often focus too much on changes the individual can make rather than on systemic problems, teaching the individual to adapt to and survive in, rather than to change, their situation. Without transforming what happens in the classroom, programmatic efforts become assimilationist as students are taught to adapt to science and engineering as usual.

Many analyses of factors influencing persistence have pointed to the importance of classroom climate and faculty-student interactions (Goodman et al., 2002; Ginorio 1995; Felder et al. 1995; Seymour and Hewitt 1997; Brainard and Carlin 1997). Recognizing the importance of what happens in the classroom, several researchers have recommended an increased use of feminist pedagogies as well as curricular reform that considers race, class, and gender explicitly (Davis and Rosser 1997; Rosser 1997; Subramaniam, Ginorio and Yee 1999).

In order for curricular reform to address race, class, and gender, one must incorporate feminist critiques of science and engineering. These critiques challenge epistemologies of science and their myth of objectivity (e.g., Harding 1986; Haraway 1991) and the hegemonies of language that reflect and perpetuate these epistemologies (e.g., Irigaray 1985; Martin 1991). When the structure of engineers' thoughts and the language used to express those thoughts are sexist, this sexism will infuse engineers' practice in profound ways.

Innovative pedagogical approaches in engineering were recently reviewed by

Osborne at al. (2008). However, most of the approaches reviewed were not explicitly feminist, focusing instead on collaborative learning, problem-based learning and other active learning approaches. Such approaches ultimately miss a critical focus on power relations (Freire 1970). Whether traditional or learner-centered, pedagogies that are not conscious of power relations teach engineers to conform to systems of power, and to operate within those systems in order to succeed; in Mayberry's (1998) terms, they are *reproductive* rather than *resistant*. Thus, unquestioning acceptance of a hierarchy of professor over student may easily lead to similar acceptance of management over worker (e.g., Vaughan 1996), male over female, or any other power structure. It may be possible to make a traditional classroom *seem* less sexist or racist, less classist or homophobic by removing offensive comments, or replacing the most exclusionary examples, or making the classroom more learner-centered. Such changes do not necessarily remove the teaching of complicity with structures of power, however, and this complicity may then be repeated within other structures that operate on hierarchies of gender, race, class, or other kinds of privilege.

Our dual project of reforming curriculum at the level of epistemology, and transforming pedagogy at the level of power relations, requires more than the common focus on persistence for women and minorities in engineering. Persistence merely requires the physical presence of individuals from underrepresented groups, while conventional science education outcomes and epistemologies are left intact. Looking beyond diversity as headcounts and considering structures of power in science and engineering requires a shift in focus from persistence to resistance.

Students and faculty practicing *resistance* might do science or engineering differently from conventional practice, seeking approaches and projects that are more socially just, that do not replicate power structures that privilege certain groups over others, that are more democratic or responsive to the needs of groups currently marginalized or ignored by science (Harding 2006; Mayberry, Subramaniam, and Weasel 2001). Of course the persistence of white women and people of color in SMET fields can be one form of resistance, as their very presence presents a challenge to discourses that render them invisible – but it need not be resistance in every case, and it is not the only form of resistance in any case.

If *resistance* is the goal, there are three things education must enable students as well as faculty to do: they must be able to identify and then challenge epistemic assumptions that make engineering unjust; they must be able to act effectively in response to their critical thinking; and, their motivation must transform from that of being disciplined as 'docile bodies' (Foucault, 1977) to empowerment as learners, questioners, and actors. Pedagogy is the central site at which these processes occur, at which students and faculty learn to think critically and act reflectively.

Experience of others using resistant pedagogies suggests that sometimes students resist the pedagogy itself and seek to re-establish conventional power relations. Insightful educators have viewed such resistance not as something to be overcome, but as something to be engaged transformatively. For example, Moore (1998) re-conceives defensive and sexist comments of a resistant male in a feminist writing class to consider both how his comments emboldened some women in the class to speak, and how his own role in the classroom was restricted by narrow notions of masculinity. Banks (1998) relates an incident in which a student's ideological resistance (in a class dealing with free black resistance to slavery in the United States), was met by the professor's resistance in challenging that position. Though difficult for both Banks and her student, the professor's refusal to make concessions to the student's position was in fact an opening for interracial dialogue in the class. Banks makes clear the tolerance of discomfort required on the part of both students and professor to create these kinds of constructive interactions, and the related risks and costs in terms of backlash and student perceptions of their professor, especially in this context of a black female professor in a mostly white classroom.

Ira Shor and Paulo Freire (1986) dialogued about student resistance to liberative pedagogies based in job anxiety – perhaps particularly salient for professional majors like engineering. Freire acknowledges the need for students to rigorously prepare for the world as it is. He sees educators as ethically obligated to deliver this curriculum, even as they are equally obligated to raise critical questions about that curriculum, preparing students to struggle for the world as it could be. This intentionally introduces a contradiction that challenges students epistemically. 'They must understand what contradiction means, that human action can move in several directions at once, that something can contain itself and its opposite also' (p.493).

In this paper we discuss liberative (critical and feminist) pedagogies and how they enable students to make the epistemic transformations necessary for inclusive science. In this discussion we draw on the literature on epistemic assumptions, theories of resistance, and our own classroom experiences. We address resistance to epistemic assumptions as well as resistance to the use of critical and feminist pedagogies in the classroom (and even resistance to challenging epistemic assumptions). We argue that any resistance to prevailing power dynamics offers an opportunity for transformation via an appreciation for more complex epistemologies. Resistance is a pivot point where student epistemic assumptions may be challenged and can thus grow with the right guidance. Changing these assumptions is central to any use of liberative pedagogies because of the ways in which a focus on power relations in the classroom inspires freedom and generates strategies and tools for resistance. It is, however, particularly important to the project of inclusive science and engineering because of the feminist project of challenging epistemologies of science (Harding, 2006). While epistemology is the tool for engaging with feminist critiques of science and the engineering

curriculum, resistance to dominant structures of power in the engineering classroom, curriculum and profession is the motivation for doing this work.

This research took place at a small, private, liberal arts college for women that started an engineering program in 2000; it was the first women's college in the United States to offer an engineering major, and one of a very small number of liberal arts colleges to offer engineering. The program's vision included innovation in engineering education, an emphasis on sustainability, and an intention to situate the major deeply in the liberal arts context. Given the track record of liberative pedagogies at this and similar schools, given the project of educating women for the traditionally male profession of engineering, and given the program's vision of innovative engineering education integrated with other ways of knowing across the liberal arts, it made sense to implement liberative pedagogies in this setting.

A narrative account follows that describes the development of liberative pedagogies in an engineering thermodynamics class. The narrative presents the pedagogical theory of liberative pedagogies and the developmental theory of reflective judgment, integrated with classroom implementation in the engineering context and brief descriptions of points of student resistance. We then present theories of resistance that speak to the narrative, followed by our methods of assessment and results that detail student experiences of resistance. Assessment results focus on the role of resistances in the learning process. What are their promises and challenges? Is there an identifiable point at which resistances clearly become 'productive'? How can resistances to classroom practices relate to resistances to epistemic assumptions? What can educators do in the face of resistances to make sure they are tapped as a creative force, and further the possibilities for transformation?

LIBERATIVE PEDAGOGIES: EPISTEMIC TRANSFORMATIONS FOR RESISTANCE.

Liberative pedagogies is a broad term inclusive of critical or radical pedagogies influenced by twentieth century educators, philosophers, and activists such as North Americans John Dewey, Myles Horton, and Maxine Greene; South Americans Paulo Freire and Augusto Boal; Europeans Jacques Derrida and Michel Foucault. The term also refers to new/revised pedagogies developed by feminist and postcolonial critics concerned with the power dynamics of gender, race and class within critical pedagogy, including bell hooks, Jennifer Gore, Elisabeth Ellsworth and others (Darder, Baltodano, and Torres, 2003).

Debates within and among advocates of feminist, critical, and anti-racist and post colonial pedagogies has been fierce at times. Questions have been raised about the nature of voice and empowerment (Ellsworth 1989, Gore 1990, Orner 1992), and who is included and who is excluded along lines of class and race as well as gender (hooks 1994). We strive to draw value from all strains of these pedagogies while fully engaging with the critiques of each.

Some may say this is too simple when the pedagogies are fraught with potential to reproduce problematic power relations. Our belief is that consciousness of power dynamics leading to the kinds of critiques currently in the literature is exactly what these pedagogies are designed to engender. We can, and should, move forward from here, never taking any one pedagogy as hegemony, especially our own.

We use the word liberative deliberately. Though the liberatory framework has been critiqued by white feminists as sexist, hooks (1994) points out that one can make the critique of sexism without dismissing the notion of liberation that sustains many marginalized people. In turn, she critiques white privilege that allows such work to be dismissed. We use it because it provokes the question – what are you being liberated from? Or to? This must be defined by individuals and groups in their specific context of time and place. We recognize that liberation is not a final 'state of being' to reach, but a constant practice of freedom; it is an expression of freedom and not its result. In engineering, this question draws a discussion of students' life goals, and calls to students' attention the potential values clash with likely employers and projects oriented nearly exclusively toward military and/or corporate profit. This opening to consider the justice implications of one's education is a critical difference between resistant and reproductive pedagogies (Mayberry 1998) – between liberative pedagogies and more mainstream cognitively-based learner-centered approaches.

Liberative pedagogies were implemented in an engineering thermodynamics course at the college. The course is required of all engineering majors and is typically taken in the junior year. Implementation was iterative, beginning with a change in classroom seating arrangement in the first year, and growing over eight offerings. Here we provide a narrative sketch of the dialectical development and praxis-based implementation process for liberative pedagogies in the engineering thermodynamics class. We hope to provide glimpses of the relation between theory and practice in our work, as well as address the institutional obstacles we encountered. We highlight the emergence of student resistance that we later theorize and characterize thematically using focus group data.

Everyday Classroom Interactions

At their core, liberative pedagogies are about developing sensitivity to power relations in the classroom. We cannot ever do away with power in the classroom; however, we can play with power relations and seek to transform those relations and learn more about freedom and resistance. Techniques for accomplishing this include attention to seating arrangements and other details of the setting's structure (Ellsworth 2005), a radically learner-centered approach that recognizes students as authorities and the authority of their experience; and sharing responsibility for learning with students.

At first, the professor (Riley) noticed that not all students were participating in class. Working with a relatively small class and flexible seating, the classroom was reconfigured to support student discussion and relationship formation. Learner-centered activities were incorporated that emphasize student authority and experience. These activities included students solving problems in small groups, presenting and discussing course material, and exploring real-world applications of their own interest. For students to benefit fully from these interactions, they need the analytical tools to understand and change classroom power relations. Students must be able to derive meaning from classroom experiences.

The biggest obstacle to implementing this aspect of liberative pedagogies is the time and energy investment. Preparing for class requires a greater level of engagement with students. There is a real letting go of power and control in the classroom. Students will not always behave as expected, and will not always be thrilled with the upending of power dynamics, particularly when it means more work for them; some remain silent and decline to participate. Institutional constraints such as grading requirements can reinforce problematic power relations that must be continually questioned.

Normalizing Mistakes

Group problem solving presented a particular challenge as, based on years of conditioning in traditional education settings, students anticipated humiliation if they did something incorrect. Increased responsibility for learning carries inherent risks. Decreasing the risk by employing group work was helpful, but not enough. Put simply, it needed to be ok to be wrong in class (Riley, 2003). Assigning and discussing examples from the history of thermodynamics in which important contributors did not have the entire story correct, yet are respected as founders of the field, modeled a scientific process that values failure as a learning tool. The instructor similarly modeled supportive ways of dealing with mistakes by using them as learning opportunities. This modeling included emphasizing the greater value of seeing how common errors develop in order to avoid them in the future, and creating an atmosphere in which questions are encouraged, especially those that offer common misconceptions to work through in class.

De-centering western and male civilization

Teaching the history of thermodynamics that paralleled the textbook evidenced the book's bias toward male Western European advancements in thermodynamics in the 19th century. Rosser (1997), among others, has identified the importance of including examples of scientists from outside of this context. A student conducted research to identify important contributions from the East historically, and from the South contemporarily, to thermodynamics. Small-scale applications and non-fossil-fuel technologies were considered to complement large industrial applications in the text. The student and the professor worked together to develop a homework assignment focused on an ancient Islamic windmill and three technologies

based on evaporative cooling in ancient India and contemporary Latin America and Africa. To counter the exclusive focus on male thermodynamicists in the textbook and history book, students profile a woman in thermodynamics of a different racial/ethnic background from her own as part of a homework assignment, and typically share their findings in class. The assignment coincides with an on-campus celebration of students of color.

These stories illustrate the relationship between pedagogy and curriculum; to change one, one must also change the other. Curriculum development requires resources to conduct research and develop course activities and assignments. An internal grant funded the student researcher on indigenous technologies. The revised curriculum, in turn, supports the pedagogical goal of epistemic transformations. Valuing indigenous technology traditionally omitted from the engineering canon presents a challenge to the epistemology of Western science. This raises deep questions about content choices in engineering education.

One type of resistance that can emerge from this de-centering work is further critical thinking about the curriculum. One year a student asked the instructor if the Montreal Massacre (a gender-based hate crime that targeted women engineers at the Ecole Polytechnique, leaving 14 women dead) was a real historical event or just an Internet invention. When the professor assured her it was an actual event, she asked why the event wasn't taught in a women's engineering program. The professor created a course activity for the anniversary of the Montreal Massacre, with a memorial (after Scanlon 1994), a viewing of news clips from the event, and a discussion that leads to important connections with the sexism and racism students experience in their own lives (Riley and Sciarra, 2006).

Institutional pressures, such as requirements to cover certain material, or pressure to conform to disciplinary norms, can pose obstacles to the work and set the stage for a different type of student resistance. Resistance to interdisciplinarity emerges to reiterate canonical messages, typically in the form of statements that what we are learning in these examples does not belong in an engineering class. For material like indigenous technologies or the Montreal Massacre to be lasting and transformative, it must address these disciplinary concerns at the epistemic level. Gender analysis of a profession is epistemologically different from force analysis of a building. For students to internalize an analytical way of thinking about power, we/they must motivate not only why this knowledge is important, but also why *this way of knowing* is important.

Critical Thinking, Reflective Judgment, and Epistemic Transformations

To understand feminist and postcolonial critiques of science and engineering, one must become aware of epistemological assumptions that underlie

science, and consider how those assumptions are problematic and how different assumptions might lead to different science (Harding 1991). For example, if one is to understand the myth of objectivity in science, one must move past epistemological assumptions that hold the scientific method as the only reliable source of knowledge.

Psychologists Patricia King and Karen Kitchener (1994) have developed a developmental model of critical thinking and reflective judgment that characterizes successive sets of epistemic assumptions individuals make as they progress toward reflective reasoning. As students develop reflective judgment, they abandon absolute certainty and reliance on external authority; pass through relativism, when all arguments seem equally justifiable, and, ultimately become comfortable with weighing available evidence and making reasonable judgments under uncertainty. Knowledge is constructed as the result of judgment decisions and must be evaluated in context to determine its validity. Knowledge is not static and must be engaged with through, for example, a process of re-evaluation in light of new data.

Liberative pedagogies address epistemic assumptions in a number of ways. First, the focus on power relations applied to epistemology creates a focus on power/knowledge – that is, the Foucauldian idea that knowledge is not independent of structures of power, but indeed power structures have a role in creating knowledge, and vice versa (Foucault, 1980). Encountering this dual relationship between knowledge and power implies student questioning of authority, including the canon, which is often invisible in engineering. In subjects such as literature, what constitutes the "great works" is openly contested; however the contents of engineering textbooks are not, even though they also represent a set of inherently political choices about what knowledge is most important. When students become authorities in the classroom, they become the ones who pose questions as well as answer questions posed to them. Students take on the freedoms and responsibilities of making judgments and evaluating data.

A reading and essay on the relationship between knowledge and power in science (Foucault 1980) were assigned, also at the beginning of the course, in order to spark discussion of power/knowledge. The course was also given the unofficial title 'Power/Knowledge' to reinforce the importance of these ideas and make a thermodynamic pun. The reading sets a backdrop for understanding later readings on the history of thermodynamics, and helps students view the course syllabus (and all course syllabi) as reflecting a set of choices made by an instructor, or a discipline (Riley and Claris, 2006). This allows students to recognize and critique the thematic content of science, and aids immensely in their understanding of entropy.

Students question, among other things, the course textbook's section on biological thermodynamics which presents unhealthy models of dieting and

gendered approaches to food; sexist and heterosexist references to the quest for 'Mr./Ms. Right'; the central focus on fossil fuel technologies and minimal discussion of climate change; and, analogies of entropy that denigrate high-entropy (less organized) learners and valorize U.S. militarism using entropy as a justification:

> 'Having a disorganized (high-entropy) army is like having no army at all…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.' (Çengel and Boles, 2008, p.355)

Reading Foucault is not easy, especially for engineers not accustomed to reading theory. In their work with the material (which extends from reading, discussion, and writing through subsequent revisiting throughout the semester), students exhibit a range of understandings of Foucault's position. Foucault's ideas are new to nearly all engineering students; the ways in which students wrestle with this material reflects their underlying epistemic assumptions and challenges them in developing reflective judgment.

Meta-level Thinking and Reflection

King and Kitchener draw on previous work of scholars such as Perry (1970) and Belenky et al. (1986) to offer a developmental model of what they call *reflective judgment*. They use the term instead of critical thinking in order to incorporate Dewey's (1933) notion of reflective thinking and its acknowledgment of uncertainty. For Dewey, reflection is grounded in personally meaningful and engaging experience, providing a further connection between reflective judgment and liberative pedagogies. A reading (Riley, 2003) and reflective essay on liberative pedagogies were assigned at the beginning of the course to create room for discussion of pedagogy and to help students understand their role in class, and why one might want to learn this way. By shining a light on the nuts and bolts of pedagogy, students are empowered to think critically about, and take part in, shaping how class is conducted. To be able to think on a 'meta-level' about what is going on in the classroom is an entry point to other kinds of critical thinking.

The practice of reflection is central to liberative pedagogies and is supported through self-directed learning reflections/blogs (Riley et al., 2006). Students are asked to reflect on new material, as a way to articulate preconceptions, and also asked to reflect on past material and pose relevant questions that take their learning beyond the textbook and classroom, into their lives. These learning reflections serve as an important form of liberative assessment – where assessment is itself a learning exercise. Earl (2004) distinguishes this

type of assessment, *assessment as learning*, from formative classroom assessments conducted by instructors to improve teaching, *assessment for learning*, and the commonplace, summative, *assessment of learning*. The reflections encourage student responsibility for learning, allow for a dialogue between student and professor (and among students), and they connect to topics that are socially or personally relevant to students. Students have the opportunity to incorporate self-knowledge in their learning. It renews a focus on process and on relationality in the classroom. As students wrestle with epistemic transformations through the Foucault assignment and in other aspects of the course, the reflections offer a window through which students can observe and question their own assumptions, and track their challenge points and growth along the way.

While liberative pedagogies supports, and even demands, a strong role for this kind of self-assessment mattering in relation to student evaluation, institutional constraints may require conventional grading or other assessment. This creates an additional burden for implementing liberative pedagogies. Students resist taking on the additional responsibility for their learning. If learning and assessment are integrated, however, it is far less of a burden because it is worked into the course in an organic way and, in fact, easier than many types of conventional assessment.

Student relevance/praxis

As previously mentioned, liberative pedagogies encourage students to engage critical thinking and reflective action, or praxis (Freire 1970). A focus is placed on inquiry, grounded in relevance and/or in student experience. In such an environment students can learn to ask critical questions and practice exploring them in a dialectical praxis relationship, where theory and practice inform one another, with an emphasis on action for change. Liberative pedagogies must be integrative and not reductionist, focusing on the whole student and diversity among students, and open to knowledge and ways of knowing from other disciplines and from outside academia.

The course was about energy. It struck the professor how much students thought they didn't know about this topic, when in fact they knew a lot about energy from everyday life experience. To make the classroom really participatory, it was necessary to utilize what students knew in a way that made them authorities. The connection to students' lives or social relevance is central to the practice of liberative pedagogies. The 'thermo-to-life' assignment required students to apply thermodynamic principles to an everyday life situation that emerged in their individual reflections.

This assignment was later replaced with one examining the relationships among hunger, poverty, and obesity in the United States (Catalano et al., 2008), which grew from a student's critique of the textbook's treatment of biological thermodynamics. In the following year the course linked with a

community-based learning course in the Study of Women and Gender – a project involving an urban farmer's market in nearby Springfield, MA, the regional food bank's hunger project, and a 6th grade public school class exploring local food cultures. Students in the Women and Gender class considered gender and labor in global and local food economies and ecologies, and developed a marketing plan for the farmer's market. Thermodynamics students collected and presented data on the energy content and energy cost of food, illustrating how expensive nutritious food is, and how poverty and hunger can drive obesity because of the relative affordability of energy-dense foods.

Again some students resist taking responsibility for learning in these contexts with open-ended problems. Obstacles at the institutional level include the additional work faculty must undertake in the absence of institutional infrastructure to remain in constant communication with partners, transport students, and generally manage the project. In some institutions, community-based learning is not seen as rigorous, or certain partners or projects not seen as worthwhile, thus engaging in such projects can itself be an act of institutional resistance.

In the next section, we will examine how different types of resistance manifest themselves in the classroom, and similarly seek to re-conceive them as transformative openings that ultimately foster the process of reflective development, the challenging of epistemic assumptions, and reflective action.

ASSESSMENT METHODS

We employed a variety of assessment techniques in the first three years of this five-year study – instructor formative and summative classroom assessment; institutional summative assessment; classroom observations; focus groups; and, interviews. Taken together, they reveal a dynamic of resistance to liberative pedagogies; however, these resistances can also be understood as transformative openings for changing epistemological assumptions and developing reflective action. Here we discuss results from focus groups, student work collected from all students during the semester, and classroom interactions, as they provide the richest picture of resistance among our data collected so far.

The focus groups were organized with volunteers from each of three thermodynamics courses offered in fall 2005, 2006 and 2007 (all students not participating as researchers on the project were invited), with 14 of 29, 6 of 12, and 4 of 18 students participating, respectively. Fluctuations in overall enrollment reflect differences in numbers of students selecting engineering as a major, and numbers of students choosing to study abroad in the junior year. The decline in student participation in the third year of the study is not easily explained; timing of focus groups and recruitment efforts were not different from previous years. The decline might be related to the introduction of a community-based learning project in the course, which

shifted some of the workload toward the end of the semester when focus groups were conducted.

Focus groups were selected as an appropriate method for capturing the sense of the class regarding the specific curricular and pedagogical innovations implemented during the semester. Questions were designed to be open-ended in order to capture student impressions on a wide variety of topics related to the course, without undue prompting or leading. Resistance was not a specific theme we set out to explore, but rather emerged unsolicited. Focus groups were conducted by a researcher who does not otherwise interact with students. Topics focused generally on how students learn in the class, including professor and student strategies; whether and how reflection assignments helped students learn, generate new thoughts, or impact student professional identity; and, what actions students undertake as a result of the class in the context of their life goals. Here we discuss those responses that relate specifically to the phenomenon of resistance.

RESISTANCE: RESULTS AND DISCUSSION

Focus group and course work data reveal resistance in a number of different settings. While we are not interested in developing categories of resistance that become positively or negatively viewed, we do wish to distinguish among experiences and settings of resistance for our discussion, and identify the context of power relations in which resistance takes place. To this end, we discuss resistance in the following contexts:

1. Critical thinking and reflective action.
2. Resistance to responsibility.
3. Resistance to new ideas.
4. Disciplinary resistance.
5. Resistance to participation.

All forms of resistance hold the potential to play a positive role in the learning process. Whether an act of resistance is ultimately constructive or not depends not only on the act itself, but also on the student's underlying motivation, the instructor's responsiveness, and peer interactions. This is not to say that all forms of resistance are 'equal' in quality or intent. Our interest here is to locate the point at which a dynamic of resistance may become productive, and examine how classroom responses can tap resistance as a creative force for learning.

Critical Thinking and Reflective Action

Critical thinking emerged without prompting as a theme in focus groups. One student discussed how she felt she was developing intellectual humility:

> "The class is helping me learn what I don't know, which is disconcerting for many students, for me it's sort of humbling, which is a good thing in my case."

Another student talked about being more reflective in her approach to problem solving:

> "Before I would just dive into problems and try to solve them right away, whereas now before I even start I take a few minutes to look at the problem and just like really think about it. I ask myself about what I know about the problem. It is interesting to me because I have never done this before until this class – I try to see how it all relates together."

Another student mentioned learning to ask questions in a self-directed process:

> "You learn how to ask questions that will enable you to learn more about thermo and take the class to the next level."

Several students mentioned thinking critically about accepted knowledge, whether that related to the textbook, the syllabus, or engineering education overall:

> "It is interesting that many of the laws of thermodynamics we simply accept as truths because they are printed in our textbooks and we assume that if they are in the textbook they must be truths."

Critical thinking related to personal levels of self-confidence:

> "I think that even as engineering students, this idea of truth coming from an institution affects the way some of us do problems. Many times we are not confident in our answers if we cannot compare with the book, teacher, or TA."

One student made a connection between engineering education and the social impacts of technology:

> "The choice of concepts [we learn] has power not only over individual students, but also over the people whose lives our engineering will influence."

Another student credited the interdisciplinarity of the course with learning to think critically:

> "Now I am more critical; about the problems we solve, about the issues we cover in class and the discussions we have there also....It was not just the sciences, the technology, and all the math behind it, it was also this other side that helped me develop these critical thinking skills."

These comments reveal a willingness to explore other ways of knowing, to interrogate authoritative truth statements, and to think more critically within the scientific epistemological frame. There is a self-reported change in behavior among some students who describe modifying how they solve problems or approach their work in engineering.

Engaging with student resistance encourages students to situate themselves within a traditionally male-oriented discourse in engineering. Students learn to challenge the sexism (racism, classism, heterosexism, militarism, and other forms of dominance) appearing both in the epistemic assumptions within science and in the pedagogical methods and curricular content they encounter as students. Students experience the tension between the tools they are being taught and the critique of those tools; ultimately, it is up to them whether and to what degree they internalize and act on the critique.

Resistance to Responsibility

Resistance to responsibility appears in student surprise at the kinds of work they are expected to do themselves. For example, in problem solving:

> "Something that she could do better would be to make it very clear what things you can assume for certain."

This highlights the changing role of the instructor and student, and the increased time investment required of students in order to think independently:

> "We're being tested on critical thinking that she really has not said ok well you have to take this whole idea and look at it this way. You can think it through but it takes so much longer."

Here students are used to a banking model in which they are given answers to store and recall, supported to a degree by the institution and profession. In our women's college context there is an additional tension between supporting students' independent thinking on the one hand and a tendency to infantilize them on the other. Within this setting, student responsibility for learning can be interpreted as resisting a sexist culture that unduly shelters or coddles students. Engineering culture supports independence in a certain way, through a masculinist notion of 'sink or swim', providing neither the answers nor the scaffolding to support student inquiry.

Resistance to responsibility for learning can be met productively with three important responses: acknowledgement of the challenges; rewarding the additional work; and, linking increased responsibility to increased freedom. Simply listening to student comments and feedback and responding with a reminder of the value that the increased responsibility brings to the student can be motivational. Additional scaffolding to support their pursuit of independent learning may be helpful in some cases where students struggle in high frustration. Ensuring that work is rewarded is very important. Often when reflections, essays, or student responsibility for leading discussion are introduced, they are not given significant weight in grading compared with technical content. This can send the message that increased responsibility for learning, or thinking in these new ways, is not actually important. To the extent that conventional reward systems are utilized in the class and valued by students, they must be directed to support pedagogical goals as much as

possible. Finally, when student responsibility for learning is increased, it can help to link this new responsibility with new freedoms as well. Emphasizing the opportunity in leading class discussion or writing reflections to focus on what interests the student, to make course material meaningful to them, can motivate students.

Resistance to responsibility then, can become the cutting edge of an expanding responsibility for learning; as it expands, students become more ready to take on the intellectual work of exploring other ways of knowing, challenging existing ideas and forging new lines of inquiry.

Resistance to New Ideas

Resistance to new ideas appears in student work that directly contradicts (as distinct from disagreeing with) the reading. For example, in an essay on the Foucault excerpt in which he argues that power and knowledge imply one another, so that the production of truth (including scientific truth) is a political process, some students misconstrue the argument that Foucault is making. Some students interpret the argument as 'scientific truth is outside of power', which is the opposite of what Foucault is arguing. Others interpret Foucault's argument as 'knowledge is power', in a simpler, one-way relationship: 'we all know that people with more knowledge have more chance to be powerful than others', or 'the only acceptable way to question truth is through scientific discourse'. A few misunderstood Foucault to say truth is relative: 'As physics tell us, everything is relative. When there is just a truth, just a statement, it is neither good nor bad because there is no other truth by which to compare'.

It is not surprising that some students wrestle with reading Foucault, because it challenges epistemic assumptions they bring to the classroom and requires a level of critical thinking and reflective judgment they may have not achieved before. For this resistance to new ideas to become productive, it is important to understand students' developmental process and challenge students where they are. Does the last quote reveal a (commonly repeated and politicized) misunderstanding of Foucault, or quasi-reflective thinking? If we ask students why they view all statements as equivalent, they may gain insight into the role judgment can play in evaluating statements (politicized or not), and thus advance their development of reflective judgment as well as their understanding of Foucault. Resistance to new ideas can become a vehicle for shedding old epistemological assumptions and exploring new ones.

Resistance to Interdisciplinarity

Disciplinary resistance appeared most dramatically in class when a student held up a reflective essay and said "THIS isn't engineering!" and held up a problem set and said "THIS is engineering!" This sentiment is borne out in focus groups in which students repeatedly voice either displeasure in the amount of writing in the course or outright concern that time spent on ethics,

reflections, and other items they view as "not engineering" will take away from, rather than enhance, their mastery of technical content: "If I wanted to be writing essays all the time, I would take an English class…I want more examples and not more essays to write." In these instances, students are challenging the instructor's assertion of what engineering is, challenging the syllabus, and asserting that they know what is appropriate for their education. Of course, they are backed by the dominant perspective in engineering education, a perspective enforced on campus in their other classes as well as in the profession at large. Still, the strength of these assertions marks experiences in which these students are coming into their own authority.

This resistance to interdisciplinarity (advocated by a female professor) in favor of practicing examples ad infinitum can be read as a resistance to a 'feminization' of engineering. Students are aware of what their male counterparts at other institutions do in engineering, where 'hard' quantitative skills are valued over 'soft' professional skills. Students are concerned about not fitting in with engineering culture upon leaving college.

The student's in-class assertion of what was and was not engineering proved to be an excellent teaching moment. On the following class day when the topic was cogeneration, the professor began with the question of why the campus had not yet adopted cogeneration in its physical plant and what it would take to achieve cogeneration on campus. Students readily identified the importance of communicating with administrators, budgetary issues, and other nontechnical skills central to changing energy infrastructure on campus or in society. Students themselves renewed their motivation for learning to write well and to understand the social contexts of technology. While not every student was persuaded by the professor's argument for interdisciplinarity, many students spoke with authority about what belonged in their education. In choosing for themselves, students assert a position against hegemony – either that of the professor's authority, or that of quantitative valorization.

Resistance to participation

Resistance to participation appears blatantly as reluctance to volunteer in class, or even reluctance to work a problem at one's desk. A more subtle form of non-participation among grade-motivated students is to follow the letter of the grading rubric but fail to comply with the spirit of the assignment, providing a perceived 'good answer' rather than an authentic reflection.

Non-participation and student disengagement can seem to get in the way of learning at times, frustrating not only the professor but also peers. The temptation to dismiss disengaged students is perhaps greatest of all. But

because motivation is the existential center from which new and liberating learnings must take place, disengagement can prove to be a most productive form of resistance.

In order for this to take place, one must apprehend the reasons for student non-participation. Silence can be a natural response to being exposed to different points of view (King and Kitchener 1994); it may reflect a fear of being wrong; or it may reiterate women's silence in the classroom (Sandler 1984).

One technique for understanding the silences is to employ non-traditional participatory exercises that bring students out of their comfort zones – in effect, to engage the silence and question it. Boalian techniques (1992), drawing on drama and improvisation, work well because the exercises are embodied (the double entendre in the title Games for Actors and Non-actors reveals the technique's power to engage non-participants). In an engineering context where problem sets are the rule, a creative literary exercise can serve a similar purpose. On a day when the College asked faculty to bring poetry into their classroom, we read a poem and asked students to construct a haiku (a three-line Japanese poetry form with syllabic construction of 5-7-5) about thermodynamics. This elicited some expressions of anger among usual enthusiasts of liberative pedagogies:

> "Just like an engine
> You sit eating your bagel
> Watching our heads spin."

This haiku critiques elements of the banking model of education, and asks, is the professor still a machine driving the axles of student minds? The professor was also writing haiku that morning, but the poem expresses the possibility that the professor does nothing but sit back and watch students work – a definite anxiety for students asked to take more responsibility for learning – is the professor just lazy? Here resistance to participation is asking an important critical question of liberative pedagogies. To be able to have a conversation about these kinds of power relations in the classroom is a direct result of techniques that allow students to travel outside their comfort zones, and an invaluable opportunity that keeps liberative pedagogies working.

> "Liberative ped-
> agogies at 9 AM
> Oh Lord what the fuck"

This was in our view a healthy expression of feelings that emerge when power relations are examined, disciplinary boundaries challenged, and students expected to engage the unexpected. The student asking "what the fuck?" is perhaps taking some measure of delight in her newfound freedom to ask "what the fuck?" in an engineering classroom, even as she is

apprehensive about the idea of writing a haiku so early in the morning.

It is important to note that these two students chose to "go meta" – to write about the classroom setting rather than about, say, entropy, as many other students did. It is this freedom, and meeting this freedom with their whole selves, we seek to encourage. It is not necessary for every student to engage in this way; as one or two students take such an approach, it is shared with the rest of the class.

An outsider to the classroom may not have known from their haiku that the students were in fact enthusiastic about liberative pedagogies. One may question if the instructor is able to tell either, given students' tendencies to be strategic about achieving high grades. A similar question applies to the case when non-participation is more subtle, with students engaging the letter of the assignment, but not its spirit. The only way to tell whether a reflection is genuine, or to understand non-participatory resistance in general, is to examine student motivation, or in Derrida's terms, to examine what precedes the question (Derrida, 2002). This means making student reflections not just personal but interpersonal, bringing them into the classroom and/or into teacher-student relationships. It is this relationality that may reveal where students are and enable one to meet them there, drawing students toward greater engagement and reflectivity.

In all of these examples, students are learning, along with faculty, to practice resistance. In some cases, we can see very directly how students' thoughts and actions present a feminist challenge to engineering – by refusing to accept the sexism, racism, classism, heterosexism, nationalism, and other hegemonies embedded in traditional learning approaches and materials in engineering. In other cases, resistance is directed in ways that may re-establish power relations of the status quo; here, reinforcing the practice of resistance and engaging further with the student to challenge underlying epistemic assumptions and their investment in certain structures of power can be transformational. If the role of women (and men) in engineering changes from persister to resister, even a group small in number may have a large and long-lasting impact on engineering education and practice. Such effects are not captured in the time frame of this study. In the long run, it will take a structural revolution in engineering to address the root causes of underrepresentation – sexism, heterosexism, and racism. Only then will issues of underrepresentation be finally resolved.

CONCLUSION

This paper has motivated the use of pedagogies of liberation in science and engineering classrooms and provided some concrete examples of how it can be implemented, using the case study of a course in engineering thermodynamics. Assessment data reveal a theme of resistance. If we can view resistance as the cutting edge of an expanding consciousness (Freire's conscientization), we see that students resisting pedagogy is the first step to

claiming authority and shedding absolutist epistemologies, to understanding that they can question classroom content and the learning process.

Implementing liberative pedagogies in an engineering classroom naturally draws student resistance because of the contradictions inherent in juxtaposing the two. A rigidly quantitative discipline with an exclusive focus on the ideas of white European males, traditionally taught in a top-down manner in order to train professionals to serve military and corporate authorities collides with pedagogies that seek to upend power relations, employ feminist epistemologies, and work toward social justice.

This is accomplished through the introduction of pedagogical and curricular changes: students solve problems cooperatively and present them to the class without humiliation; students bring their everyday knowledge to class and learn to claim authority in the field; students encounter and explore the people and technologies who contributed to thermodynamics who are not European males; students apply thermodynamics locally, collaborating with community organizations, middle schoolers, and students who study women and gender.

As such these changes represent challenges to structures of power at multiple scales (classroom, institution, discipline, profession, society) and it is therefore not surprising that they would induce resistance in students. In this specific context of a women's college preparing students to enter the hyper-masculinized profession of engineering, there is anxiety about transitioning successfully out of a single-sex environment into a male-dominated one. Some students resist challenges to male power in the profession, re-asserting the exclusive value of quantitative and technical material and de-valuing interdisciplinary work. Women's socialization supports student resistance to responsibility as learners. The acceptability of women's silence in the classroom – still operational even in an all-women's classroom – supports resistance to participation.

Coeducational and mostly-male classrooms would reveal different power relations and different stories of resistance. Pedagogies of liberation are designed to help classrooms confront issues of privilege and oppression. In coeducational contexts there may be more to work with in the everyday classroom, as gendered interactions may provide very direct opportunities to discuss sexism. At the same time there may be more discomfort in doing so, as the risks may be greater when such interactions are necessarily personalized.

In the introduction we asked what educators can do to facilitate resistance as a creative force for transformation. It is important to understand resistance in terms of students' epistemological assumptions, and to continually engage and work with student motivations for resistance. Power relations become part of the curriculum. In our case, this meant explicitly discussing student

anxieties around transitioning from a women's college to a career in engineering, as in the Montreal Massacre exercise. We demonstrated the practicality of professional skills and challenged the presumption that only technical content matters in a relevant example - cogeneration on campus. Creating opportunities for students to reflect on their own learning allows them to take more responsibility for learning. Classroom exercises that take students out of their comfort zones (for example, using theatre or poetry) can break student silence and invite participation.

The instructor must maintain compassion for students and not grasp at power, even in the face of students demanding 'education-as-usual'. This means that the teacher shares his or her own critical engagement (constructive resistance) with content and pedagogy, thus modeling what is expected of students and re-motivating liberative learning. The point at which resistance becomes productive is when students and faculty become reflective and skeptical of knowledge claims, including their own, and wrestle consciously with power relations.

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