Power/Knowledge: Using Foucault to promote critical understandings of content and pedagogy in Engineering Thermodynamics

Abstract

Thermodynamics is a subject area in engineering that is deeply relevant, as it deals with energy use in society. However, students often struggle to connect their experiences of energy with course content traditionally based in theoretical discoveries from 19th century Western Europe. The work of French philosopher Michel Foucault is similar to thermodynamics in that its abstract poststructuralist theory strikes fear in the hearts of students, but can be made deeply relevant when its understanding is grounded in one's experience.

An excerpt from Foucault's *Power/Knowledge* discussing the "regime of truth" was used to stimulate critical thinking about the course content. In a reflective essay and class discussion, students considered the relationship between power and knowledge in thermodynamics and beyond. Analyzing student responses to the Foucault reading and regular course reflections reveals a significant shift in their understanding of classroom pedagogy, an increase in critical thinking about the course and its subject matter, and an emergence of independent ideas that students pursued further in the course.

Introduction

Engineering students continually confront the challenge of bridging the gap between theory and practice, between curriculum content and learning process, between their engineering education and their future professional lives. The connections students make between their education and their personal lives is most often untapped. Using liberative pedagogies (processes that empower students in their learning through active engagement and self-reflection), the engineering thermodynamics course at Smith College has been revised to promote the relationship between thermodynamics and student experience.[1] Student engagement with the classroom innovations aids the learning process and provides an opportunity for students to take responsibility for their learning. Thus, an excerpt from Foucault's *Power/Knowledge*[2] discussing the "regime of truth" was introduced to stimulate questions exploring the course content and the learning process, as well as to emphasize the ultimate goals of liberative pedagogies, critical thinking and reflective action.

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. 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 apply knowledge of thermodynamic principles in design
- An appreciation for the philosophical, cultural and academic structures that have created the current understanding of thermodynamics, as well as the implications of thermodynamics for those structures.
- 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 ability to assess and direct their own learning, and to reflect on that process.

Liberative pedagogies were employed in thermodynamics because of their emphasis on process, with attention to the establishment of a community of intentional learners, and building transformative student-student and student-faculty relationships. The use of such pedagogies can address a series of contradictions in traditional engineering education that are implicitly at work when learning becomes detached from student experience, including:

- Students naturally seek connections between their education and their personal lives, yet they are hardly ever able to bring what motivates them to pursue engineering in their formal studies.
- What and how students learn is often detached from or even contradictory to engineering practice or the real world.
- Students are expected to work together harmoniously, yet they may not know or like each other.
- Students are urged to cooperate, yet they often work in individual or competitive situations.
- Students are encouraged to be creative, innovative, and independent thinkers, yet they are also expected to conform to both the instructor's and the curriculum's dictates.

A central problem of engineering education is that too often students are prevented from relating authentically (academically, socially, emotionally, and creatively) to the subject matter at hand and to one another. They can feel pressured to know definite procedures rather than engage creatively in a process of exploration, seeking instead to rely on memorization of definitions. This detached way of learning is not preparing students to be effective engineers, because it undermines many learning objectives related to problem-solving, self-direction, critical thinking, verbal and visual communication, ethics, and consideration of social contexts and impacts.

Paulo Freire in a dialogue with Antonio Faundez[3] described a "castration of curiosity[*]" in which questions are not asked, by instructors or students, out of fear. The student fears ridicule or embarrassment, while the instructor fears the answer to the questions or sometimes the question itself as an inconvenience or challenge to authority. This creates a detached learning dynamic in which, Freire said, "the educator, generally, produces answers without having been asked anything." Antonio Faundez responded "Exactly! And the most serious thing, Paulo, is that the students get used to this way of working."

Liberative pedagogies ground learning in student experience, making connections where traditional engineering education detaches. According to Freire, "The student must discover the living, powerful dynamic relation between word and action, between word, action and reflection."[3] It is important not only *that* connections are made, but also *how* they are made. Liberative learning is fundamentally *relational,* both in terms of connecting theory and practice, content and process, and in terms of emphasizing human relationships in the classroom and in the world as central to learning. Typically a relational learning approach[4] identifies three different ways that an individual student has of relating; the learner's relation to themselves, the learner's relation to the teacher, and the learner's relation to the world (this includes the academic and social aspects of the classroom).

Liberative pedagogies view process and content not as oppositional, but rather bring the two together and relate one to the other explicitly in the process of learning. The point is to bring theory and practice, content and process, together and not only show how each depend on the other, but also to empower students to engage academically, socially, emotionally and indeed creatively in the learning process and in the world around them. We wish for students to ultimately see this engagement as a relation between power and knowledge, one that is interwoven in what, how, and why they study. This engagement with relational learning addresses the problems of detached learning.

By being relational, liberative pedagogies open new doors for assessment approaches, ones that actively involve students and are fully integrated with the learning process. Detached learning depends fully on students' measurable abilities for our assessment of them. At best, it focuses exclusively on outcomes; at worst, it bean counts hours spent covering topics, numbers of problem sets completed, and the like. Liberative pedagogies must be evaluated in terms of process as well as outcomes. An integrated assessment tool can simultaneously be a learning tool to promote critical thinking.[5]

All of this represents a paradigm shift in the classroom, in terms of content and pedagogy. In implementing liberative pedagogies in the thermodynamics classroom, a number of course activities were developed to place thermodynamics in historical context, raise questions of ethics and policy, de-center western civilization, promote student authority and responsibility for learning, and establish a democratic classroom that encourages all voices.[6]

Thermodynamics can be particularly frustrating for engineering students, because it reflects one of the key contradictions of engineering education; it is a subject that ought to be immensely practical and relevant, being fundamentally about energy. However, perhaps not coincidentally,

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[*] We recognize that Freire's language is problematic from a gender perspective.

engineering thermodynamics is often taught as one of the most theoretical courses, abstract and detached from its applications, obscuring its relevance and its importance for most learners. The applications themselves can often prove less than satisfying to students, who find the idealizations of internal combustion into standard air power cycles an abstraction too far. Even when applications are made salient, learning things in a practical and applied way does not necessarily engage students liberatively. This is particularly the case when the focus on the practical does not incorporate relational learning, self-reflection, or critical thinking. Such high-order thinking is encouraged when students are engaged in a process of asking questions, both common ones that they share with their peers and their own that go beyond the course material into their personal lives or into their engagement of the real world. Questions must be welcome outside of the course material, including those that challenge the traditional questions that are typically asked, as well as those that consider the process of how questions are asked and answered in and out of class.

Such changes in content and pedagogy are only meaningful if they are accompanied by a shift in student awareness and intentionality about what they are learning and why they are learning it. The implementation of liberative pedagogies requires engaging with the canon in engineering, which necessarily implies a liberatory process of questioning; students must join in and take ownership of this process. Such involvement is necessary not only for students to experience these activities as more than extraneous work, but also because it is an essential aspect of the learning process under liberative pedagogies.

The engineering education community has not deeply engaged questions of canon, with the result that the curriculum is often disconnected from what students really care about. For example, on the first day of class, students expressed interest in topics such as alternative energy, global climate change, and technological investment for future energy concerns. However, core course concepts remain grounded in fossil-fuel-based steam power and internal combustion engines. Some texts have made an effort to connect with student concerns, but because the canon is unquestioned, these are usually presented as add-ons. For students who have a strong interest in internal combustion, they are often disappointed by how idealized representations do not connect well with their experience of real engines.

It is essential for students to understand the engineering course syllabus as selections from a broader topic area, selections subject to the particular interests of the instructor, or of accreditation boards and future employers of engineers. Students ought to view a syllabus critically and understand that choices are made to include certain items and leave others out. Such critical thinking skills are essential for engineers, who may face professional situations in which critical thinking protects both their reputations and the well being of the client, employer, or the public. Students should similarly pose questions about the learning process. Why are assignments selected, and how do they support learning in light of their goals and motivating questions as developing women engineers?

In a tribute to Foucault, the instructor gave the course (Engineering Thermodynamics) the unofficial title “Power/Knowledge,” to make considerations of truth and power central to the discussion (and to play on the thermodynamic concept of power as an energy rate).

Working Foucault into Thermodynamics

The objectives of introducing Foucault in thermodynamics were to:

- Stimulate critical thinking about the course
- Lay groundwork for connections made later about the history of thermodynamics, and course content including the second law
- Support the use of liberative pedagogies
- Give students an opportunity to reflect on engineering and society, science and truth, etc.

The work of Michel Foucault, like thermodynamics, is both abstract and highly relevant when grounded in personal experience. His work can provide insight regarding how choices are made about what students learn in engineering, especially who the decision makers are, what motivates them, and what that means. An excerpt from Foucault's *Power/Knowledge* discussing the "regime of truth" was selected in part because it dealt directly with the role of science in forming our society's truths ("'Truth' is centered on the form of scientific discourse and the institutions that produce it"), as well as the political forces that control its production and transmission. This was intended to lead students to question the politics of what questions are considered in science and how society decides what counts as truth, and thus stimulate critical thinking about the course content. Indeed, the process of engaging with Foucault can in itself promote critical understandings, if students take the necessary time to ponder, question, and discuss his arguments.

This assignment was contextualized in several ways. The first day of class students filled out a pre-assessment in which they free associated items they thought of when prompted with the word "power" and with the word "knowledge." This was used as a springboard for discussion about the class, its content, and its pedagogy. The week before reading Foucault, students were introduced to liberative pedagogies in class and through course readings[1] and a reflective essay. On the first day of class, students were introduced to the syllabus as one representation of what is important in thermodynamics, not the definitive word.

In a reflective essay and class discussion, students considered the relationship between power and knowledge. The essay prompt read: "What is/are the relationship(s) between power and knowledge? Is knowledge the same thing as truth, or how does it differ? How does this relate to the course (both the subject matter and how it is taught or learned)? Be concrete." The assignment was evaluated based on a 50-point rubric, with 10 points allocated to each of the following: writing quality, documentation and support, critical thinking, engagement (making connections among engineering practice, engineering in society, and the student's life), and substance (addresses question, provokes further thought, demonstrates deep reflection).

In subsequent class meetings, the relationship between power and knowledge or between Foucault's ideas and thermodynamics resurfaced frequently. For example, Foucault can provide background on the nature of truth that helps students understand the multiple statements of the 2^{nd} law, which can be confusing. Students were better able to understand why Carnot's fascination with steam power led to statements of the second law grounded in heat engines, while subsequent statements by Clausius became more abstract due to a quest for parsimony and elegance. It also supported students' critical reading of the textbook's presentation of entropy analogies, discussed below.

Analysis

We collected a variety of evidence of student engagement with the ideas of Foucault. First, there was the pre-assessment in which students shared what came to mind when presented with the idea of "power" and "knowledge." Second, the students completed a reflective essay on the Foucault reading they were assigned. Third, students were asked on a test to critique a passage in the textbook. Fourth, students completed an end of semester evaluation in which they answered an open-ended question about what the phrase "power/knowledge" meant to them. These data were analyzed using textual analysis of student writing on the pre- and post-assessments and essays. There were other points of input from focus groups conducted with 14 students in the thermodynamics course (47% of the class) with the goal of discussing pedagogy, and unsolicited feedback from individual students about the course.

Results

First Impressions: Students were asked to answer two questions on an introductory survey on the first day of class "What do you think of when you think of the word power?" and "What do you think of when you think of the word knowledge?" Class discussion began with eliciting student concept associations with power, and student concept associations with knowledge. The results are shown in Table 1. Some students took notes on the brainstorming exercise in class and wrote down some of their peers' associations, driving up the counts for some concepts; it is interesting to note that no two forms were alike, because students chose to write down some terms and not others. Perhaps this is a reflection on note-taking styles, or perhaps some students wrote down terms that particularly resonated with them. When asked to relate the two concepts, some related Bacon's statement that "Knowledge is Power" to their choice to pursue an engineering education. Others confronted the idea that "Power is Knowledge" to question the slant of thermodynamics texts toward the use of fossil fuels. Some connected the Power/Knowledge discussion to the use of liberative pedagogies, which strive for more level classroom power dynamics.

Class Discussion: After reading the three-page excerpt, a class discussion wove together ideas from Foucault with discussion of the ideal gas law. It began with an acknowledgement of the difficulty of the reading, and a discussion of why Foucault is hard to read -- because he and his contemporaries (like Derrida) were concerned with the ways in which language itself, or words, are imbued with power. Foucault often consciously presented things in a non-traditional, nonlinear way, and pinpointing exactly what he is saying can be elusive at times. One has the experience of following for a while but loses the argument from time to time, because it is not possible to have the same mind as Foucault – and that is, in a way, the point.[7]

Next, students were asked to share with their groups what they wrote in their reflective essays about the relationship between power and knowledge. Specifically they were asked to share:

- A concrete example from their experience of the relationship between power and knowledge
- A connection between power/knowledge and the thermodynamics course

Table 1: Associations with Power and Knowledge in an Introductory Survey			
Power Associations	Mentions	Knowledge Associations	Mentions
Knowledge	23	Understanding	21
Work	20	Experience	19
Force	17	Power	17
Money	17	Freedom	17
Fuel	16	Books	17
Influence	14	Wisdom	16
Energy	14	Communication	16
Leader	14	Independence	15
God	12	Education	15
Politics	11	Respect	15
Watts	10	College	14
Sin	9	Joy	13
Arrogance	9	Information	13
Physics	9	Perspective	12
Power plants	9	Autonomy	11
Engine	8	Propaganda	9
President/G.W. Bush	8	Contemplation	8
Electricity	4	Utilitarian	6
Leadership	3	The past	6
Wanted by many but accomplished by few	2	Research	6
Strength	2	Learning	6
Transportation/Travel	2	Decisions/good decisions	5
How fast it can go	1	Things working well	4
How much work can it do	1	Thought	2
Problems	1	Teachers	2
Potential	1	Future	2
green house gases	1	Tolerance/Acceptance	2
Math	1	Connection	1
Lightning	1	Ability to make things work well	1
Authority	1	Truth	1
Creation	1	New	1
The amount of energy needed	1	Reason	1
Napoleon Bonaparte	1	Can't be taken away. It's empowering.	1
electrical generation of power	1	Thinking	1
Rock	1	History	1
Time	1	Interest	1
Skills	1	Life	1
power ranger	1	Work	1
motion/movement	1	Confidence	1
ablilitiy to do work	1	Balance	1
Sun	1	Effective action	1
ability to provoke change	1	System	1
financial Strength	1	Class	1
Engineering	1		

Students were more engaged during this discussion than at any other point in the semester – so much so that it was difficult to get the smaller groups to come back to report out to the group what they had discussed. Discussion began with the Baconian idea that knowledge is power; students reported concrete examples of how knowledge gives one power. One student noted that knowledge can be controlled by powerful people and that this can limit freedom in society. The instructor directed the discussion toward the thermodynamics class and challenged students to consider who controls what they learn in thermodynamics. One student commented "ultimately it's what we put into it. People take what they are told because it's easier than thinking for themselves. I mean, it's TRUE."

The instructor shared with the class the importance of asking who decides what is learned, and noted that the question of the canon doesn't get discussed often in engineering. This led students to share reflections related to pedagogy within the class.

In the same 80 minute class, during a discussion of ideal gases, the instructor asked students to consider the power/knowledge relationship in ideal gas theory. That is, they are initially taught $PV=nRT$ in high school as an absolute, and not until a thermodynamics class do they confront real gases, and learn about other equations of state. The instructor asked whether other equations of state were "more true" because they apply to a greater range of gases than the ideal gas law. This all reinforces important points for engineering students about knowing the assumptions behind theories they apply and equations they use. The class discussed the strong preference science has for an elegant equation that can summarize complex physical relationships concisely and mathematically. This set the stage for later discussions about the development of entropy.

Reflective Essays: Student responses reveal that nearly all understood Foucault's points that truth is "a thing of this world," that it is produced by "multiple forms of constraint," and that it "induces regular effects of power."[2] Many students gave concrete examples of how this is true in their experience, reflecting a solid understanding of Foucault's argument. Galileo's defense of heliocentrism was mentioned most frequently. White House assertions about the existence of "weapons of mass destruction" to justify U.S. involvement in Iraq was the next most common example. One student cited the Navy's dismissal of bombshell actress Hedy Lamarr's torpedo guidance system, another the Scopes trial, and another the eye doctor's power in deciding what kind of vision is considered "normal" or "corrected." Another student offered her belief that abortion causes breast cancer as a truth that is suppressed by the power of the pro-choice medical establishment.

Some responses did not reflect a complete understanding of the nuances of Foucault's work, presenting a more naïve relationship between power and knowledge. For example, one student described the relationship as "linear," and a few seemed to only view the relationship as one in which knowledge provides people with power. One student wrote, "we all know that people with more knowledge have more chance to be powerful than others…" Another said, "the more knowledge we acquire, in this course, the more we have the ability to hold power or do powerful things. But it is often the more knowledge we have of these accepted truths that will grant us power."

A small number of students misread Foucault with a rudimentary interpretation of truth as relative, allowing one to believe whatever one wishes, with no acknowledgement of critical thinking or other means of determining for one's self what one believes. "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." Ironically, given Foucault's *History of*

Sexuality[8], another student presented as equally valid two views on homosexuality – one that accepts sexual orientation as an aspect of diversity and one that pathologizes it as immoral and unhealthy.

The chosen Foucault passage dealt directly with science’s role in the complex relationships between truth and power. Some wondered what the science establishment accepts or rejects today that might result in future embarrassment. One wrote, “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. The scientific society determines what is and is not true, not the individual scientists.”

Others failed to see science as an institution, treating it as pure and separate from society. “Science always moves forward, making new advancements, and discovering new truths. I believe the truths in science are more real than the truths in society. Truth in science is closer to fact, whereas truths in society are rules.” Some adopted an Althusserian view[9] that science is a pure path to truth not subject to effects of power: “Every institutional leader, such as presidents, religious leaders, and people of the elite possess power thanks to their knowledge. Their knowledge is their truth. Yet they have the power to establish the rules that will generate our truth. The only acceptable way to question this truth before such [a] system is through scientific discourse.” Students wrote about the need to trust others to know what is true. One did not recognize her own agency in this, but another noted “we can use our knowledge to determine if we believe these truths…”

Interestingly, no one raised current debates about climate change as an example, which would have been appropriate to thermodynamics, science in society, and ways in which individuals and institutions wrestle over truth and power. The instructor raised this in class after the assignments had been turned in. Other connections were made to thermodynamics; one posited a case in which renewable energy advocates had more power than fossil fuel proponents: “People in positions of power who have invested in renewable energy sources, could try to influence society into believing that there is an energy crisis, for their own gain.” One student brought up “the inventor who claims to have invented a perpetual motion machine. Having knowledge of thermodynamics will allow us to question what we are being told and know when we are being lied to rather than simply believing everything we are told…”

Several students connected the Foucault reading to course content. “The concepts we learn as students are most likely the ones we will later on be most comfortable with as engineers. This means that the choice of concepts has power not only over individual students, but also over the people whose lives our engineering will influence.” Another discussed the use of assumptions in engineering which may or may not be true, but are often accepted without question. “Perhaps in taking this class…I will better understand why we learn the things we are taught, instead of just swallowing it down like a bitter pill because `[it’s] what I have to do.’” Students recognized that the textbooks don’t necessarily contain the whole truth: “Knowledge isn’t just education gotten from textbooks (because these too then become a source of influence) but to me it seems more like a medley of experiences with everything from science to culture that has led someone to think critically and understand [why] they do what they do.” Students also spotted truth-power dynamics happening within engineering education: “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 …" Students readily made connections to liberative pedagogies. Most were able to do this in a way that reflected a correct understanding of these pedagogies and their implementation in the course.

- "…each individual student acts as the power source and the professor merely acts as a facilitator to knowledge. It is the responsibility of each student to take action…."
- "It is imperative to remember that we have the ability to challenge whatever might be presented to us as the truth. Regardless of this course being scientifically based, we are being handed the power to criticize it as much as it needed."
- "Liberative pedagogies give the student the power over how their knowledge is gained. In this way the delivering institution is not deciding the paths to the truths and understanding that will ultimately by reached. The path and therefore the resulting truth will be gained at the discretion of the gatherer of knowledge."
- "This course is taught in such a way that students must be active participants in their education. Instead of accepting the current truths, we must challenge and wrestle with them."

Some made the connection to diversity:

- "With these pedagogies, course material is presented from not only one perspective (i.e. that of the dominant male, white population). Different perspectives are going to be considered: that of females, people of color, and people from different cultures. In this way, the knowledge or truth presented in the course will not be biased and will be closer to what actually exists."
- "If the information being learned, taught, and understood as factual statements at present are based upon the political economy of truth, then the need to broaden the diversity of those who affect the structure is an obvious necessity. The evolution of education will affect the evolution of the political economy of truth…"
- "Very few women are represented in engineering and our class is specifically geared toward educating women to be successful, creative engineers..."

However, not all understood how the power relationships between faculty and students were being leveled by the pedagogy. It may be that some students were merely skeptical that power can be shared in the classroom, and that students come in with a great deal of knowledge based on their experience of the world. In other cases there may remain a strong expectation or desire for engineering instruction in which instructors retain power:

- "The teacher of the material, Dr. Riley, will have power over us as students, as she has more knowledge about the subject."
- "In the classroom the professor has all the power because they have all the necessary information that must be disseminated to students."
- "Those who have gained knowledge through their education have the power to create rules, regulations, and truths for students to follow. Students have some power within these truths to accept or reject ideas that have been established. Students gain knowledge until one day when some of these students are now responsible for determining what truths are taught to the next generation."

Other more generic problems with the assignment included students not understanding jargon (misuse of words like “discourse”), not expressing their thoughts clearly in the essay, a lack of support for arguments or clarity of argument, and difficulty relating the abstract material to concrete experience in their lives or the class.

Test Question: Student internalization of the thinking in Foucault’s work was evaluated using a question on the second test in which students were asked to critique a passage in the textbook in which the authors present entropy analogies that are thermodynamically questionable and have certain social implications. The question tested critical thinking skills as well as students’ understanding of entropy and its appropriate application, and the ability of students to understand social implications of engineering. This question had the highest average on the test, with a median score of a perfect 10 out of 10. Students took most umbrage with the authors’ descriptions of high and low entropy learners – in the words of one student, “the use of entropy as a category that can potential[ly] diminish people labeling them with the stigma of `disorganized’ is definitely a conflict between truth and power… Who determines that a person with short term memory has more entropy in her life than a person who stores information very easily?” Students also critiqued a passage that suggested that high entropy armies are useless and that the U.S. is the most powerful country in the world because it is made up of 50 states unified into one country, rather than being 50 separate countries.[10] Many picked up on the value judgment the authors made that low entropy or organization is better than high entropy or disorganization.

Final Evaluation: The final course evaluation administered the last day of class posed the question “What does the use of the alternative class title Power/Knowledge mean to you?” Results are presented in Table 2. We categorized responses by their reflection of (1) a full Foucauldian sense of Power and Knowledge influencing each other, and its implications for learning thermodynamics; (2) a simpler Baconian sense that knowledge is power, or knowledge brings power to students in some way; or (3) a non-responsive answer that reflects neither understanding. The category with the greatest number of responses (13 of 28) reflected the broader Foucauldian relationship between power and knowledge, with most students (9) making connections to course activities (discussions of ethics (2), social impact (6), reflective blogs and essays (2), dynamism of class (1)). Four mentioned liberative pedagogies, learning how to learn, and how power/knowledge dynamics play out in the learning process. Perhaps the most complete answer was as follows: “We increased our knowledge about power (ha ha). I think the class gave us the power to think about things critically; also to think about what consequences our actions have and how to reflect about yourself as a learner.”

While nine of the 28 responses were categorized as reflecting the Baconian Knowledge/Power relationship, only two of these reflected the pre-course simple notion that knowledge brings power, with the other seven reflecting more nuanced understandings of this relationship. Four wrote about empowerment as learners, that is, that the class was about learning how to learn, or learning intentionally. Three mentioned empowerment based on applying what they learned to the real world (reflective action). One mentioned empowerment as a woman.

Table 2: Student end-of-semester responses to "What does the use of the alternative class title Power/Knowledge mean to you?" N=28					
Foucauldian Power/Knowledge	**13**	**Knowledge is power**	**9**	**Non-Answers**	**6**
Course Activities*	9	Empowerment as Learners	4	"I don't know"/"nothing"	3
Liberative Pedagogies	4	Empowerment through reflective action	3	Blank	2
		Knowledge is Power (Bacon)	2	Thermodynamics is related to energy for sure	1
		Empowerment as a woman	1		
* Course activities mentioned included relating thermodynamics to its social impact (6), ethics (2), reflective essays and weblog (2), and the dynamism of the class (1).					

Focus Groups: Two key themes emerged in the focus groups related to this aspect of the course. The first was a fear expressed by some students that the emphasis on liberative pedagogies -- including the Foucault assignment, weekly reflections on both technical content and ethics, and essays on topics including Foucault, liberative pedagogies, and women in thermodynamics – would take away from their technical education. This view was expressed by two or three of the participants. As one put it:

If I wanted to be writing essays all the time, I would take an English class. This class was good if you wanted to be well rounded and if you want to be a good writer but I don't think that's the right class for it because I feel I have hard enough of a time trying to understand the material, I want more examples and not more essays to write.

Other participants (in greater numbers) expressed a clear recognition that critical thinking was an important goal in the class and something students felt they learned to do better (although it was not always clear that they had the same understanding of critical thinking that we do). One student put it this way:

What I have noticed throughout this class is that my critical thinking has been changing, and I believe that's good. Now I am more critical; critical about the problems we solve, about the issues we cover in class and the discussions we have there also. There have been so many deep thoughts that have come to me that I don't think I would have had or would have seen things that deeply if I had not taken this thermodynamics class. 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.

Other Observations: One product of students learning to question the syllabus is that it generates dissent in the classroom. Students would regularly ask why they had to write essays in a thermodynamics class, or why they had to engage in ethics reflections. In the instructor's experience this occurred more in this course than in other courses where essays and reflections were presented in a more top-down way. The instructor saw the student questioning as positive, because it provided continual opportunities for discussion with students, and reminders of the need for this work within the context of thermodynamics. In particular, as stress levels increased going into the Thanksgiving break, there was a pointed incident in which a student held up one of her graded essays and said emphatically “THIS isn’t thermodynamics, then held up a problem set and said “THIS is thermodynamics!” In the next class, on cogeneration, the class was able to spend some time talking about a real-world application of thermodynamics that has great relevance on campus, as Smith is considering retrofitting its physical plant to become a cogeneration facility. A 15 minute discussion of Smith’s situation and the factors that influenced Smith’s past decisions not to move to cogeneration as well as its current favorable consideration of the option brought out reflections on Foucault, political and economic considerations, the need for good communication, ethical decision-making, and other factors. The class then brainstormed in groups and shared the kinds of preparation an engineer needs to work on a cogeneration project. Students themselves noted the importance of liberative pedagogies and the need to read and understand Foucault, engage in writing and ethics exercises, and so on.

Another outcome of reading Foucault in thermodynamics was a student approaching the instructor about the Montreal Massacre, the mass murder of female engineering students that occurred in 1989 at the University of Montreal.[11] The student asked the instructor whether the events actually took place, as she had read about them on the Internet and could not ascertain whether they really happened. When the instructor said they had, the student asked why at Smith College, the first women’s college to offer engineering, students wouldn’t learn about this important event in women’s engineering history? The instructor decided to observe the anniversary of the event in the thermodynamics class[12]. The class watched news footage of the event and an interview with one of the female survivors five years later. Discussion focused on the words of the killer: “You’re women. You’re going to be engineers. You’re all a bunch of fucking feminists. I hate feminists.”[13] The survivor interviewed had actually tried to explain to the killer that they weren’t feminists, just women trying to learn engineering. This led to an interesting discussion about the conflict between “being a woman” and “being an engineer,” what it means to be a feminist, and the significance in this context of Smith as a women’s college offering an engineering major. This student approaching the instructor and requesting that this material be taught was very likely a product of the environment created by the use of liberative pedagogies and the inclusion of Foucault.

Discussion

It was well worth the time to teach Foucault in the context of the thermodynamics course. We drew on the material from Foucault throughout the semester. It aided in student understanding of technical material, but more important, it provided a depth of understanding of the pedagogical methods used in the class that improved the learning process, engaged students, and fostered their critical thinking. The Foucault reading provided a theoretical background that made sense of liberative pedagogies, intentional learning, the goals of critical thinking and reflective action, and the choice of essays and reflection assignments used throughout the semester.

Foucault and the other nontraditional elements of the course were not popular with all students, but they did engage a set of students who may not normally be excited about a core thermodynamics course.

It will be important in future offerings of the course to provide students an opportunity to compare the content received in this course with thermodynamics courses at other schools. It is the case that we cover more than most first courses in thermodynamics, with a stronger focus on the mathematical underpinnings of thermodynamics, because our degree is in engineering science and we cover both mechanical and chemical engineering applications in a single semester. Once students understand that they are not being shortchanged on technical material, and in fact are able to learn more deeply because of the focus on the learning process, they may be more receptive to Foucault.

As discussed above, student questions of the syllabus, learning process, and assignments illustrate the benefit of both the pedagogies and the reading of Foucault. Connections to liberal arts courses are made clear through the use of Foucault, a popular author in many social science courses on our campus. One student noted that it gave her a way to connect with her peers over dinner, and gave her a way to talk about her engineering courses that was non-threatening to the non-engineers. This may in the end be one of the greatest contributions of this element of the course; to open conversations with non-engineers about technical material.

Conclusion

Analyzing student responses to the Foucault reading and regular course reflections reveals a significant shift in their understanding of classroom pedagogy, an increase in critical thinking about the course and its subject matter, and an emergence of independent ideas that students pursued further in the course.

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