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Pushing the Boundaries of Mass and Energy: Sustainability and Social Justice Integration in Core Engineering Science Courses

Dr. Donna M Riley, Virginia Tech

Donna Riley is Professor of Engineering Education at Virginia Tech

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Abstract

My presentation, part of a special session panel discussion on integrating social justice in core engineering courses, discusses lessons learned from specific attempts (in two courses over several years of teaching) to integrate social justice considerations in sustainability instruction. As the session description notes, most sustainability education in engineering has to date done a thorough job ensuring student learning about the relationship between sustainability considerations and the economic bottom line, but has done far less in considerations of people and communities, rarely taking up questions of power and equity.

In my presentation I draw on my experience developing, teaching, and assessing modules in collaboration with colleagues in the Engineering, Social Justice, and Peace network to integrate social justice considerations in our core courses. I reflect on lessons learned from two assignments in two different core courses, each implemented in the larger context of engineering at a liberal arts college. Here introducing a social justice dimension of sustainability was a small part of a larger effort to integrate liberal education into core courses.

One module introduced students in a first year Mass and Energy Balances course to the tool of Life Cycle Assessment (LCA) for developing and analyzing green products and processes, while simultaneously offering a critique of green consumerism which was incorporated into student LCA projects. A key learning outcome was that students understood not only the promises of the tool but also its limitations and when it is and is not appropriately used.

A second module, in Engineering Thermodynamics, sought to integrate considerations of climate change, ethics, and global economic inequality. The course, taught in the fall semester, usually overlapped with a major international climate summit. Using the 2009 Copenhagen summit as case study, students analyzed the conflict between countries in the global North and global South, with guided prompts and background reading to aid them in understanding and incorporating into their analysis the power relations evident in the climate talks, borne of histories of colonialism and present-day neoliberal economic policies. This case study was among several ethics assignments offered throughout the semester, and in some years was part of a wider exploration of global climate change. Taken as a whole, the ethics assignments and reflective engagement of students produced gains in critical thinking and reflective action, along with resistance from some students policing disciplinary boundaries of the course, opening space for motivating conversations about the syllabus in the context of the larger engineering program.

The presentation concludes with some lessons learned related to design of assignments, motivation of social justice topics, scaffolding for specific social justice concepts and terminology that may be new to students, challenges of transforming an over packed curriculum, and how student resistance to topics perceived as “not engineering” can be a positive learning opportunity.

Introduction

Sustainability has emerged as an acceptable theme in many engineering education contexts over the past two decades, with an earlier history dating back to the 1960s.[1] While environmental engineering was the logical home for sustainability and has driven a great deal of the movement for sustainability education in engineering, disciplines like chemical engineering and mechanical engineering have also risen to the challenge to incorporate sustainability considerations in teaching their discipline to undergraduates.

However, definitions of sustainability in engineering have been more technical in nature than definitions used in other disciplines, and more focused on technological solutions. Material taught in engineering courses on sustainability tends toward the quantitative. Mainstream definitions such as that put forward by the Bruntland Commission[2] are presented with little time focused on dissenting definitions.[3] Environmental justice considerations are largely absent, despite clear relevance to engineering.[4]

As part of a community based learning grant funded by Campus Compact, members of the Engineering, Social Justice, and Peace network developed learning modules for engineering core courses that addressed different aspects of social justice issues.[5] One of the modules I developed as part of that project explored the class dimensions of Life Cycle Assessment and Green Product Design in a first-year Mass and Energy Balances course. While the LCA project was offered several times, the iteration including the class dimensions of green products was offered only once and not offered subsequently due to changes in departmental teaching assignments.

The second module was developed initially in the immediate aftermath of the Copenhagen Climate Summit in 2009 in which the G77 countries made clear in no uncertain terms that they would not accept climate solutions that perpetuated colonial relations and increased global economic inequality by constraining the global South without a leadership commitment from the North .[6] While that particular Copenhagen summit remained the most useful case study due to the clarity of expressions of North-South global inequality and its relationship to colonial histories, each subsequent year presented new real-time insights into the same dynamics that deepened the case study and lent it continued currency.

Module 1: Life Cycle Assessment in Mass and Energy Balances

Course Context: A semester long project in Life Cycle Assessment (LCA) was implemented in a second-semester first year mass and energy balances course. The course prepares students to formulate and solve material and energy balances on engineering systems and lays the foundation for subsequent courses in thermodynamics, fluid mechanics, and advanced electives in thermochemical processes. More fundamentally, it introduces the engineering approach to problem solving: breaking a process down into its components, establishing the relations between known and unknown process variables, assembling the information needed to solve for the unknowns, and finally obtaining the solution. The project provides an introduction to the systems perspective in engineering, basic information literacy skills for engineers, and the application of mass and energy balances to life cycle assessment. During the course students learn to use structural frameworks for thinking about engineering ethics, which were at that time woven throughout the engineering curriculum. These included both the more typical frameworks such as duty ethics, utilitarian ethics, virtue ethics, as well as more advanced frameworks from environmental ethics (different ones emphasized in different years) including ecofeminist ethics, morally deep ethics, ethics of care, social justice frameworks, and deep green resistance.

Learning objectives included basic engineering calculations and computation, material and energy balance calculations, including applying these principles to product life-cycle assessment; working effectively in a learning community; using a variety of ethical frameworks to think critically about ethical problems in the engineering profession; and developing information literacy skills as well as self-directed and lifelong learning skills.

Description of Module: The LCA assignment was adapted from one presented by Nair[7] and expanded into a semester-long project designed to ask questions about the class dimensions of green consumerism. In the first iteration, students were asked to focus specifically on beverages and based on student feedback the topic choices were relaxed in the second iteration. In the second iteration the project was also fully integrated with a campus-wide initiative to infuse information literacy into curricula.[8]

The semester-long assignment asked students to explore the LCA tool in order to compare two or more similar products to determine which is more sustainable, using mass and energy balance principles. Typical LCAs consider things like cloth vs. plastic diapers; bottled vs. tap water; cremation vs. burial; or organic apples from some distance vs. locally produced conventional apples. The assignment explores the use of the LCA tool and its limitations. Students are reminded that LCAs do not account for all social, cultural and economic contexts or impacts, and are asked to take a critical view of the tool to determine when and how -- or whether -- it is best used.

Objectives for the assignment included:

- Explore the use of product life cycle assessment as a tool for determining which of two or more similar products is more environmentally friendly
- Apply mass and energy balance principles in an open-ended context
- Explore the limits of LCA as a tool, in light of economic, social, ethical, cultural, and political considerations
- Build information literacy skills
- Develop reflective judgment and critical thinking

The assignment is broken into several parts with staggered due dates over the course of the semester. Students deliver the following:

A. A reflection on why it would be important to conduct LCAs, and where they might be helpfully applied in real-world contexts.

B. A description of the products to be compared and how they are used locally, with particular attention to similarities and differences among products.

C. Initial research on manufacturing and use of the products, beginning with extraction of raw materials and ending with ultimate disposal. A written narrative description of the life cycle, along with assumptions, alternative assumptions and the environmental consequences of those assumptions.

D. Flowcharts showing the material, energy, and residual flows for product production, use, and disposal.

E. Annotated bibliography detailing sources, with minimum numbers of peer reviewed sources of different types, all categorized by source type. Reflections on sources, their usefulness and the relative reliability and quality of sources.

F. Criteria for deciding on the "better product choice" considering:

- What do sustainability terms (resource conservation, environmental quality) mean and how are they best measured?
- What other factors would you have to consider in addition to resource conservation and environmental quality to determine the better choice?
- Can you propose the weight each of these criteria should have? Are there strict percentage weights, or are there some criteria that are must-haves or "go/no-go"?
- Outline the set of values that you have considered in developing your criteria.
- How might the criteria (or their weights) change with the culture of the society developing and/or using the product?
- What may be the problems in translating the factors determined by these criteria into changes in the design of products?

The central deliverable for engineering and social justice considerations was a 3-5 page ethics reflection in which students identified an ethical issue within their LCA topic. Students followed the ethical analysis frameworks they were taught elsewhere in the class (in this case the "traditional" frameworks typically found in engineering ethics texts such as duty ethics, virtue ethics, and utilitarian ethics, as well as some forms of ecological ethics such as Johnson's morally deep ethics). They identified relevant facts and values, the range of positions one could take and how each could be supported by ethical principles. Then they were asked to select and justify a position. All prompts suggested to students probed social justice aspects of LCA:

- Should a person buy the "more ecological" product?
- What is the ethical responsibility of engineers in the creation of "more ecological" products? How is this responsibility shared with others, such as consumers, or policymakers? What are the limits of this responsibility?
- Is it ethical to charge a premium for ecological products? What are the ethics of the class

dimensions of green consumerism?

- Is it ethical to market a product as green if it only meets certain ecological criteria?
- Is consuming to demonstrate environmental commitment hypocritical?
- What ethical considerations (e.g., related to labor, or to economic structure and policymaking) does LCA leave out that ought not be ignored?
- Americans use the mantra "reduce, reuse, recycle" while Nicaraguans use the phrase "refuse, reduce, reuse, repair, recycle." Why do you think "refuse" and "repair" are not part of the mantra in the United States? What are the ethics of including or excluding "refuse" and "repair"?

Outcomes: By the end of the term, students submitted product LCAs, presenting in both oral and written formats, and concluding which product is more sustainable based on their criteria. Students were asked to reflect on their criteria and suggest any changes based on what they learned, to assess whether choosing one product over the other would make a significant difference in the long run, and to reflect on whether they individually would do anything differently as a result of what they learned.

Students gained experience applying mass and energy balance concepts from the course to an open-ended, real world problem by estimating the materials and energy resources embodied in everyday products, as well as the waste flows and emissions to the environment during manufacture, use, and ultimate disposal of the products. Students learned to use concept maps, tables, flowcharts and other visual aids to show the environmental burdens/impacts.

Reception: Generally speaking, the Life Cycle Assessment project was well received in this course. Students enjoyed the focus on sustainability and the project's real-world relevance, particularly in contrast to problem sets:

> *This class totally inspired me, especially the part we are doing now with the life cycle assessment. I thought it was really interesting to first learn all these things about material and energy balances and then have the opportunity to use it in a way that I can see might be useful in real life. So I thought it was really interesting.*
>
> *I like the class. It's interesting material. It forces me to look at things in two ways. With the life cycle assessment I've come to realize that there is another side to something all the time. And I have to find that in order to make the right decision or make a clear decision. So I think that it's helping me develop another type of mindset – I think that's a positive thing.*
>
> *I don't think the problems we're doing make a difference but what we're doing now is life cycle analysis and I like the research for that.*

Students accepted the questions about the tool's limitations, and did not focus centrally on them. Negative comments instead focused on a desire for more structure in the project, or more time, or a smaller more manageable problem. This is something of a "hide the vegetables"[9] approach to social justice, where its going unnoticed may also mean its impact was somewhat limited.

Module 2: Global Climate Change

Course Context: An ethics case study I developed explores global economic inequality and the North-South divide in Climate negotiations. It was first introduced in Engineering Thermodynamics in spring 2010, and repeated in three subsequent offerings of the course. This particular case study is a single assignment in the form of a 2-3 page paper analyzing the case study, and one of several (3-4) similar case study analyses conducted over the course of the semester to meet the course's objectives related to the last (but not least) course objective below:

- An intuitive understanding of thermodynamic processes in engineering practice
- The ability to solve engineering problems in thermodynamics
- The ability to assess and direct your own learning, and to reflect on that process.
- An appreciation for the philosophical, historical, cultural and academic structures that have created the current understanding of thermodynamics, as well as the implications of thermodynamics for those structures.
- The ability to relate thermodynamic principles to everyday life
- The ability to think critically about thermodynamics and engineering ethics

The course maintains a central focus on the thermodynamics "canon" – first and second laws, properties of pure substances, and the application of these principles in internal combustion engines, steam power plants, refrigeration cycles, and the like. Because thermodynamics is fundamentally about energy, it has been possible to integrate considerations of current topics in energy and climate in order to support lifelong learning and reinforce technical concepts with socio-political context.

The course has long been highly experimental in nature, having been the site of numerous innovations related to implementing critical and feminist pedagogies and integrating liberal arts topics in the setting of a core engineering course.[10] As such it is difficult to impossible to ferret out the impact of this particular innovation in the context of others, and that is not the goal of this piece.

Description of Module: The Copenhagen case uses Livingstone's[6] coverage of the 2009 climate talks in Copenhagen, which points out the increased risk of significant damage in the global South, where limited government resources will affect countries' ability to adapt. The piece quotes Lumumba Di-Apping, then chair of the G77 group of developing nations, calling a 2 degree rise in temperature a "suicide pact" for Africa. The G77 challenged the global North to offer development funds supporting renewable energy infrastructure in the global South, as well as leading the world in carbon emissions reductions. From their perspective, energy is essential to development and necessary to lift people in the global South out of poverty, meet basic human needs, and resist the history of colonialism and present-day neoliberal policies that created and perpetuate global economic inequalities.   Students are asked to analyze the ethics of the Copenhagen agreement (or lack thereof) from a variety of philosophical standpoints and stakeholder perspectives using a common structure used in other ethics case studies throughout the course and in other courses in the four year curriculum.[11]

Outcomes: Because it was always offered as one of several options of ethics assignments, the students who chose Copenhagen tended to be internationally minded, interested in policy, interested in climate change, or interested in global inequality issues to begin with, at least more than those students who did not choose the case. The student work on Copenhagen tended to be engaged and of high quality, most likely because it is based in a current topic, and connects to ongoing climate talks in subsequent years. For students interested in other climate issues such as campus divestment, the Copenhagen case study challenged them to consider the role of colonialism historically and current neoliberal economic policies in exacerbating climate problems.

This is not the only place social justice issues have been introduced in the thermodynamics course, as long-term implementation of critical and feminist pedagogies necessitated many changes over a decade of teaching. Students considered questions of inequality at multiple points throughout the semester, and the Copenhagen module was one such point. Other projects included various renditions of an assignment on hunger, poverty, and the energy cost and energy density of food.

Taken as a whole, the reflective engagement of students in thermodynamics produced gains in critical thinking and reflective action, along with resistance from some students policing disciplinary boundaries of the course, opening space for motivating conversations about the syllabus in the context of the larger engineering program.[12]

Reception: The reception of the Copenhagen case study cannot be separated from reception of larger projects occurring in the course related to both Climate and Ethics, which met with a great deal of resistance from students in 2010, in stark contrast to previous offerings of the course. This was particularly surprising to me: in a program whose central tenet was sustainability and in a northeastern geography where the realities of climate change went unquestioned, I was taken aback when students began in 2010 – in the ninth and tenth offerings of the course -- to state that climate change discussions did not belong in a course on thermodynamics. My focus on climate had previously worked well a unifying theme, and in this iteration I hoped it would allow me to examine ethics, communication skills, and a semester long energy project simultaneously, providing a cohesiveness around engineering, energy, and the environment.

However, student perceptions were strongly against climate in both spring and fall 2010, perhaps because of the topic had been made more central than before. In earlier years where sustainability and climate were brought into Thermodynamics in relation to it being an overarching theme of our engineering program, but a secondary theme in thermodynamics, it was generally well received. It may be that sustainability concerns are accepted on the margins, but not in the center, where they threaten the engineering canon more directly. In the context of a course that explicitly discusses and challenges the engineering canon as part of its larger pedagogical mission, it may also be that students feel empowered to push back, and they do not believe climate change is part of the thermodynamics canon because it is not incorporated in their textbooks or in courses on other campuses.[12] This may be the expected result of pushing the boundaries of mass and energy, and when student dissent can be discussed openly in the classroom, it can be a productive site of learning for everyone.

Despite the overall resistance from the class, some students found the larger climate projects to be life-changing. Two groups of students became vegetarian or vegan for the fall 2010 semester as part of their project teams' strategies for their semester-long experiment in effective carbon reduction. Some found the exercise engaging, challenging, and powerful from a learning perspective, and a few even chose to remain vegetarian or vegan for good.

Discussion

What lessons can be shared from these examples?

Challenges of the Overpacked Curriculum. First, it is possible to include social justice in core technical courses without undermining the core technical content. In the case of Mass and Energy Balances, Rich Felder, author of the course textbook, worked with me to identify which topics were essential to cover to meet the desired learning outcomes for the course and for the students in our program. We chose to place more emphasis on some topics than others. These are choices everyone makes, though not always consciously. To make this process explicit, thoughtful, deliberate and participatory with other faculty who build on the course can be truly liberating. A similar process occurred in Thermodynamics at multiple points in time. It is not course content, but the emphasis on coverage for its own sake, that presents the obstacle. Releasing ourselves from coverage obligations (whether externally or internally imposed) pays off a hundredfold in opening up endless possibilities for a course.

Design of Assignments. Building assignments in forms students recognize and feel are achievable is essential when asking them to go outside their comfort zone in other ways. The LCA assignment was built into the course as a semester long project, broken out into manageable bites due the same time as problem sets, in alternating weeks. LCA utilized and unified technical course content with communication, ethics, and other learning outcomes. It made sense logistically and pedagogically. The Copenhagen assignment took the form of case study because students learned in the Mass and Energy Balances course how to do case analysis and were asked in other core courses to do case studies related to each course topic.[11] However, as teaching assignments changed and new faculty came on board, there was significant drift away from teaching ethics both in the Mass and Energy Balances course and in the rest of the technical core, which could account for some of the resistance.

Scaffolding for New Concepts and Terminology. Providing scaffolding to students to help them understand what is expected as they work with new concepts and terminology is important. Taking time in class for students to work with new concepts and terminology is invaluable, as is providing clear evaluation rubrics. It can be helpful to include a draft due date and peer feedback activity to help improve student work and build confidence with new concepts and terminology. These approaches were used in both courses, and more fully in the first year course. As students began to come into Thermo not having had experience with ethics case studies, it became necessary to take additional class time to teach students how to approach them. This emphasizes how "it takes a village" and scaffolding extends beyond the confines of a single course, and working with faculty who teach prerequisites can aid student comfort and preparation significantly.

Motivating Social Justice Topics. Helping students understand why questions of social justice are being posed in the course is crucial. Connecting to student experience, contemporary issues of interest to a variety of student backgrounds and career aspirations can broaden the receptive audience. Outside authorities who represent destinations to which students aspire, or whom they respect, can carry more weight than the course instructor many times. Helping them connect to students in other majors, or faculty in future courses they might take, can be motivational. In both Mass and Energy Balances and Thermodynamics, students were asked to reflect regularly on their learning, which created opportunities for students to find within themselves a place of connection and engagement to course topics, including but not limited to social justice.

Student Resistance and Learning Opportunity. Compared with the LCA, the Copenhagen assignment is much smaller and shorter in duration so would be expected to make less of an impression on students. Were it the only encounter in the course with Climate Change (or with Ethics, which draws a similar reaction that it "does not belong" in Thermodynamics), it might be better received by students, but with less impact. It is interesting that in the first-year mass and energy balances course, both the LCA project AND ethics were well received by students, with ethics being cited as students' favorite course element with LCA a close second. Why so different for thermodynamics students, who are mostly juniors? One possible explanation mentioned above related to the change in scaffolding of ethics, and possibly also climate change, in the curriculum. Another possibility is that students have a stronger set of expectations about the canonical content in a core course like Thermodynamics than in Mass and Energy Balances, which, while considered part of the core, is nonetheless part of the first year curriculum and maintains the flavor of an introductory course. Another possible (and likely related) explanation may be found in Erin Cech's work documenting progressive disengagement of engineering students with respect to ethical and political issues over their undergraduate years.[13] Since the findings are based on data drawn from engineering students at this same institution (along with three others in the same state), albeit a few years earlier, it is reasonable to assume these trends apply and may be a factor here.

Regardless of the reasons for resistance, it is important that faculty meet resistance in a spirit of openness and recognize resistance as a moment ripe for transformative learning. I have written about this elsewhere[12] so will only relate from that piece my favorite illustration of this phenomenon from the Thermodynamics course. Just before Thanksgiving, a student frustrated with an essay assignment held up her essay and exclaimed, "This isn't thermodynamics!" and then held up a problem set: "THIS is thermodynamics!" I did not say much in the moment, as I was taken aback, but upon reflection, realized that by bringing it into the classroom, the student had given us all a learning opportunity. The next class session was on the topic of cogeneration, and the campus was at that time discussing retrofitting the physical plant for cogeneration. The technical analysis was clear on the high efficiency of cogen plants over conventional design. I asked the students why they thought the College had not yet opted for cogeneration, and what it would take to convince the Board of Trustees to make the investment. Immediately what came up were politics, economics, communication skills, organizing strategies, and more. The students themselves articulated why all of that DID have something to do with Thermodynamics, and more importantly, with their future lives and livelihoods as engineers and as citizens.

Conclusion

Teaching social justice in core technical courses is risky because it challenges the engineering canon and engineering's epistemological assumptions. In both of these, when done right, it also raises questions of power and privilege that manifest in engineering knowledge and ways of knowing.[14,15] To seek to address these questions is most definitely to touch engineering's "third rail." While it is necessary to start small and build social justice into a course over several offerings, impact is achieved when one is able to scaffold key concepts and reinforce principles throughout the semester, and ideally over multiple courses. Many faculty would seek to avoid touching the third rail and try more incremental or circumspect approaches that do not get at the heart of the power relations problem with engineering and social justice. These projects are not to be undertaken lightly, and their costs are very real. However, they worth doing because dealing with power and engineering knowledge in core courses stands to be transformational for students, for the profession, and for the practice of engineering education.

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