2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #32638

Implementing Social Justice Projects in Thermal System and Mechanical Design Courses

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Abstract

Topics and assignments related to social justice were integrated into thermal systems design and mechanical systems design courses with the goal of disrupting the social/technical dualism present in engineering curriculum that often discourages engineering students from learning about and participating in social justice issues and discussions. Using a modular four-step process the social justice assignments have students engage in engineering analysis while at the same time considering the impacts of the engineering technology on different groups of people. The first iteration implementing the modules in a thermal systems design course showed student engagement in the topics, and overall, a positive experience for the both the instructor and the students. The next steps for this project are to incorporate social justice modules into a mechanical systems design course, continued incorporation in a thermal systems design course, and perform qualitative analysis on the course artifacts and student feedback.

Introduction

This work-in-progress paper describes a curricular intervention designed to incorporate various topics and assignments related to social justice into a thermal systems design course and a mechanical systems design course, both taught in the mechanical engineering department at a large, public institution on the west coast. Specifically, the two instructors (and paper authors) have adapted material from Dr. Donna Riley's "Engineering Thermodynamics and 21st Century Energy Problems: A Textbook Companion for Student Engagement" [1].

There are myriad definitions of social justice, most of which support the idea that social justice is a value or belief that people should have equitable access to resources and protection of human rights. Most definitions argue that power imbalances result in structural and social inequities and that society should work toward empowerment with people from disempowered or disadvantaged groups [2, 3]. In practice, social justice looks like actively changing institutions, policies, and economic or government structures that perpetuate harmful or unfair practices, which eventually restrict access to resources. It also involves changing the regularities of a system or the way things are typically done. This might involve reconceptualizing problems from an ahistorical or asocial perspective. It could involve confronting an authority figure who represents power [4].

The curriculum intervention described here is in response to some students and faculty within our department who have recently called for a broader engineering curriculum, within (not separate from) their mechanical engineering courses. For example, in thermal/fluids courses we discuss fundamentals and design of systems, but rarely do we consider the full effects of designs or technology on the environment or society. We evaluate designs based on "will it work" and a company's bottom line but often do not consider other costs such as environmental, and determining who benefits and who is perhaps hurt by a new technology. In mechanical systems design courses, one of the main materials we study in machine design is steel. We consider many properties of steel such as strength, stiffness, weight, and hardness. However, we seldom consider other properties, such as the enormous amounts of energy required to produce steel, the communities from which steel is mined, and other impacts such as the health risks to workers in steel manufacturing plants.

By making issues of social justice within core engineering courses explicit, we are hoping to 1) engage students in the discovery that issues such as energy policy, sustainability, mining practices, bias in design, etc. are not separate from engineering practice, 2) disrupt the social/technical dualism present in engineering curriculum that often discourages engineering students from learning about and participating in social justice issues and discussions, and 3) empower students to learn how they can work towards social justice in ways that support their professional development and career plans.

Study Context

Thermal Systems Design is a required, senior level, thermal capstone course. Students have completed all other required courses in thermodynamics, fluid dynamics, and heat transfer. Course topics include engineering economics, design of piping/pumping systems, designing heat exchangers, system simulation and optimization. Mechanical Systems Design is a required upper-level course focused on the analysis and design of components including gears, shafts, bearings, clutches, brakes, fasteners, and springs. In this paper, we will describe the modules that were developed and implemented in the thermal systems design course in Fall 2020. In addition, three modules are under development for the mechanical systems design course that will be implemented beginning in Spring 2021; the first of these modules is discussed here. We also describe students' reactions to the modules in thermal systems design.

Engineering Thermodynamics and 21st Century Energy Problems

Riley's text, "Engineering Thermodynamics and 21st Century Energy Problems: A Textbook Companion for Student Engagement," is more than a companion text. It is a call to action for both students and instructors to engage with the subject of thermodynamics not because it's just another mandatory rung on the ladder toward an engineering degree, but because energy matters. Application topics include transportation, manufacturing, nutrition and exercise, electric power, HVAC, and many more. Right now, in the middle of a global pandemic brought on by Covid-19, the First and Second Laws of Thermodynamics are directly relevant to the manufacturing of our much-needed vaccine, as well as its transportation and storage. When we present opportunities for students to think about thermodynamics (or any other engineering subject) in this way, it becomes relevant, interesting, and important in a way that takes the topics past the text book and into the world we live.

Riley wants us to reconnect with our passion for lifelong learning and to take ownership of our choice to study engineering—to attend university in the first place. Harnessing this commitment, passion, and ownership can enable engineers to actively participate in the development of new technology while recognizing the enormous political, social, and environmental factors related to energy production, availability, and use. While Riley's text does not promote a certain political stance or agenda, it does challenge students and instructors to critically examine the intersection of thermodynamics, and social and environmental justice. In this way, it provides a pathway to meet ABET student outcomes 2, 5, and 8:

2) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

5) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

8) an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Riley's text uses a modular format that engages students in a four-step process (Engage, Analyze, Reflect, and Change).

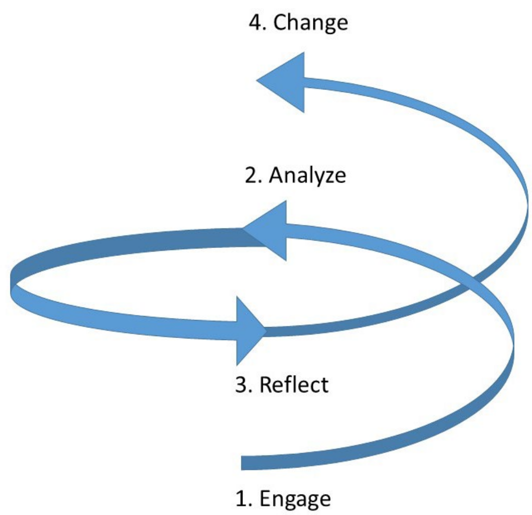

Figure 1: Learning Process for Modules

The modules presented in Riley's text can be integrated "as-is" into typical thermodynamics courses. However, as the modules are not prescriptive, they can be modified for a variety of courses beyond thermodynamics–for example, Mechanical Systems Design, as is illustrated in this paper.

Thermal Systems Design: Module Descriptions

For the thermal systems design course, six of the modules were adapted directly from assignments in Riley's text [1] and seven based on the format of Learning Process outlined in Figure 1. All Thermal Systems Design modules revolved around energy. The following table lists the module options. Students were given the option to choose their topic—to help ensure buy in for the project—and they did four of the modules in Table 1 over the term in three assignments. The students had the choice of three topics for Assignment 1, seven choices for Assignment 2, and two choices for the second part of Assignment 3. Project 2 had too many options, and for future courses the choices will be limited to three options. The most popular topics for Assignment 2 were "Clean Water Access" and "How Solar Panels are Made," which were each chosen by 5 teams, and "Building Decarbonization," which was chosen by 3 teams.

Table 1. Description of the Thermal System Design Modules

	Topic	*Description*
Assignment 1	World Energy Use [1]	Students had to consider and research current energy use in different nations around the world and consider why the United States is a disproportionate consumer, even among highly industrialized nations.
	Women, Poverty and Energy [1]	Students examined the relationships among energy, poverty and gender inequality, critically questioning the conventional wisdom about the role of energy in development.
	1 kW per Capita? [1]	Students documented their energy use for a week and tried to answer the questions: "What would it take for you to live on 1 kW?
Assignment 2	Oil and natural gas pipelines	Students investigated the needs of pipes, safely moving oil/natural gas options, who influences where the pipelines go, the environmental impact, and economic cost/benefits.
	Clean water access	Students investigated water pipelines, including Flint, MI and other locations.
	Refrigerant choice	Students investigated refrigerant impact on environment and safety including who has financial stakes in what refrigerants are used, and how are policies made.
	Native Alaskan Village Needs	Students investigated the needs of Alaskan villages, including the costs for technological improvements, who should pay, and how the US government and Native Alaskan tribes can partner.
	How solar panels are made	Students investigated what influences the cost of solar panels (financial, environmental, etc.), especially to make them affordable for US customers.
	Booster power plants	Students investigated the need to maintain electrical services, and what the impact of solar and wind energy is on current power plants (operation/financial/etc.).
	Building Decarbonization or Electrification	Students investigated what it would take to decarbonize buildings including investigating barriers to decarbonization, technology needed to overcome the barriers, and determining what actions need to be taken so that decarbonization efforts are (social/ racial/ economical) equitably done.
Assignment 3	Developing Selection Criteria for Energy Technologies [1]	Students were asked to generate a set of criteria to use to evaluate and select energy technologies. (All students did this Module)
	Power Generation Technologies [1]	Students applied their selection criteria to 4-6 power generation technologies to evaluate and compare. They needed to be specific about the type of plant, and in some cases, the type of fuel as well.
	Transportation Technologies [1]	Students applied their selection criteria to 4-6 transportation technologies to evaluate and compare. They chose an intended application then mixed and matched choices of vehicle types, power source, and thermodynamic cycle as appropriate.

For each module, the students were asked to **engage** in a topic by reading given material and/or searching for material on their own. To help the student recognize biases, they were asked to categorize all their references by gender, and ethnicity or race. Then students had to **analyze** a process or situation related to the topic, which may have been technical or social, quantitative or qualitative. Next, students were asked to **reflect** on a particular question or on what they had learned from the analysis. Finally, they were challenged to initiate some type or **change**, either to their way of thinking or in the world at large as a result of what they had learned. The process is iterative, as shown in Figure 1, and students were told that they may still have additional questions at the end, which is okay and expected. The end product of each module was a written report in which the students discussed their answers to the posed questions in each of the Engage, Analyze, Reflect, Change sections. All modules were completed in teams of two to three students.

For example, for the Clean Water Access module, students were tasked with finding reliable resources to research the topic of water pipelines in Flint, MI and other locations in the United States. For the **Engage** section of the report they needed to answers questions about whether there is a pattern (social/racial/economic) of who in the US does not have access to clean, healthy water: "What is the government's role?" "Engineers' role?" "And who pays for it?" For the report, the students summarized their findings and wrote an introduction so that someone unfamiliar with the Clean Water Access topic could understand it—the major issues, current and historical problems, and the current state of technology. They were also asked to identify authors who are male, female, White and POC and list all references and categorize the authors by gender and race. Then they discussed if there a difference in view points and how having more than one type of voice was important for understanding Clean Water Access in the US.

In the **Analyze** section, the students determined what sort of calculations, including economic, and visuals were need to tell the story of Clean Water Access and present the data. By the end of the Engage and Analyze sections, students' goal was to ensure that other readers could understand conflicting sides of the issue in the report.

For the **Reflect** section, students were asked to write individual reflections on what they had learned in the Engage and Analyze sections. Here they answered the following questions. "What are your opinions about the issues?" "How did your opinions change while doing the assignment and discussions compared to what you thought or knew about the topic before the project?" "Is there a difference in viewpoints of your reference authors?" "How is having more than one type of voice important for these topics?"

For the **Change** section, students could write from personal or team consensus point of view and answer the following questions. "What changes should or need to be changed to ensure everyone has access to clean water?" "What can you personally do?" "Is there something your profession should be doing or you can do in your career?"

In addition to the written report, in the middle of each project—after the students had a chance to start the engage and analyze sections—students were assigned by topic for a live (zoom) inter-team discussion. The discussions gave the students a chance to discuss their progress so far and ask questions. The discussions were led by seniors who were majoring or minoring in Ethnic Studies and had experience talking and learning about social justice issues and technology. They also met with the instructor before the live discussion for training and details about the project topics. The student discussion leaders were chosen outside of mechanical engineering in order to give a different perspective in the discussion. After two of the three live discussions, the students participated in an online (graded) reflection/discussion exercise. The first post required the students to answer the following four questions:

1. Tell us why you choose your project option. What made it interesting or important to you?
2. What did you learn during the zoom discussion?
3. What question(s) do you still have?
4. How can you incorporate what you learned in the zoom discussion in your report for the project?

Then each student had to reply to at least two peers' posts and do one of the following tasks:

1. Give ideas for how they can answer their question(s).
2. Share some feedback to their thoughts about their project.

Finally, for one of the projects, the students completed peer reviews of each other's reports. Each student read, graded and gave feedback on two other reports. The purpose of the peer reviews was to allow the students to learn about topics they did not choose and to learn from their colleagues' reflections and change sections.

Mechanical Systems Design: Module 1 Description

To date, one module has been developed and is ready to pilot in Mechanical Systems Design. This first module, "The What and Why of Mechanical Systems Design," was adapted from Riley's text directly. The basic premise of the module is that no one enters a class knowing absolutely nothing about a subject, and we want to connect students to the idea that they can already speak with some authority on mechanical systems design before engaging in the formal course curriculum.

The module follows the same four-step learning process (engage, analyze, reflect, and change) as described earlier, although it has been adapted to fit the mechanical systems design context.

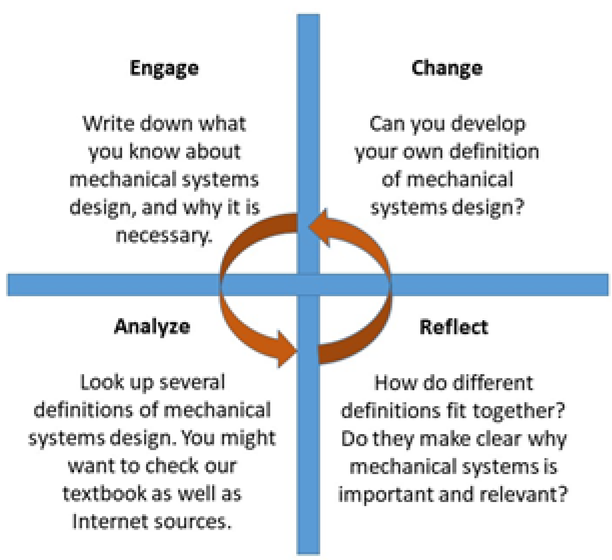

Figure 2: Learning Process Adapted for Mechanical Systems Design

In the **Engage** step, students will explore what mechanical systems design means to them by establishing a definition of mechanical systems design that 1) draws from their own personal understanding; and 2) synthesizes other definitions in their textbooks and on the internet. This step recognizes that students already have knowledge of something that they may otherwise think they could only earn through the class and technical textbook.

Next, in the **Analyze** step, students examine these definitions and determine if they think that they address why mechanical systems design is important to our world today. Then, in the **Reflect** step, students will question what is often missing in "expert" definitions of mechanical systems design and begin to think critically about how information is presented in classic engineering textbooks. They may look into how mechanical systems impact humans, and the role of engineers in influencing these impacts.

Finally, in the **Change** step, students synthesize their personal definition and research to develop their *own* working definition of mechanical systems design. This definition includes what they believe are the centrals parts of mechanical systems design. Students now have a chance to pause and pose questions such as "Why am I in this course and why might it be important?" "What should I be looking for and how might that change over the duration of the course?" "Is this engineering and who is it for?" It may also initiate critical thinking about why they are in this class and a university student more broadly. Students may even begin considering groups of people that may have been left out of the definition or starting to think of themselves as someone who can contribute to machine design.

Author Positionality

We are teachers and researchers at a public, four-year university. Both authors identify as White, cisgender women, and are assistant professors in mechanical engineering. Each author is actively involved in diversity and inclusivity improvement at their university and in their department, through workshops, training and book circles.

Preliminary Results and Discussion

Overall the integration of these unique projects in the thermal systems design course was met with excitement and interest. Students told the instructor that they agreed that engineering was more than calculations and that thinking about technology and engineering in a new way was not only interesting, but also a change in pace from typical engineering projects.

As expected, there was also some student push-back. In the official student course evaluations, a few students expressed disappointment that they did not get to do the large design project that they heard about from previous students, or that the social justice projects did not feel “engineering” enough, i.e., they were more like research papers and not what they considered what was expected in an engineering design course. What is promising is that the criticism was from a small number of students, and understandable from students experiencing this sort of integration of topics for the first time in a traditional engineering course.

The project reports were high quality, as would be expected from senior college students. What was most interesting were the reflections, change suggestions and comments during discussions. The following are a few selections from the online discussions and final reports.

Students recognized the importance of the topic is more than the engineering solution:

> We chose the clean water access project because it represents a socioeconomic issue that most of us don't think about every day, but is extremely prominent around the world, even in our country.

Some students discussed what the roles of the engineer is to be able to solve problems that seem to be the job of the government and non-engineers:

> This paper really opened my eyes to that and has helped me gain a better understanding of who everyone’s roles are, whether it be an engineer, the government, a company, or your own.
>
> If we [engineers] showed the government these [newly designed] systems that have a high performance to value ratio, it would be a win for the government and the communities that get to benefit from their new water supply. This proves that as engineers, our work and design have the ability to affect and help people on a national scale.
>
> As engineers it is our responsibility to come up with ways to educate persons and change lifestyles, invent new water conservation technologies or develop energy efficient desalination plants. There are many careers in the water preservation industry for mechanical engineers. I know engineers that work for county utility services that assist in preserving and maintaining our water clean.

Students also recognized their own biases in doing the analysis and making judgements.

> I think your question about what advancements people have made in terms of water access really depends on your definition of what a successful advancement is.

Identifying and acknowledging biases while doing the projects was a big step for these students and many discussions emerged about how to address biases as engineers. These discussions were great teaching moments and helped to show the instructor and students the importance of these topics in an engineering course.

As discussed, the project was not meant to be the end of the discussion but the beginning of a discovering their role in society, and students still have questions about how to be a part of the solution as engineers.

> A question I still have is if we know it can be more difficult for underdeveloped cities/towns to have access to clean water whether the roadblock be the government, money, or logistics; why can’t we come up with other sustainable options?
>
> I want to further research what type of engineering solutions, besides the obvious lobbying and advocating for science behind clean water? Can we design pipes that corrode less easily?

Finally, we saw some change in how students approach these topics from an engineering point of view: recognizing the value and importance of different human perspectives:

> I think what has been most moving throughout this project is realizing the importance of voice and personal narrative. In all the engineering-related analyses I have worked on before, it was important to not rely on emotion, "gut feelings," or any other observations that are not directly tied to tangible numbers. I think that even though engineers strive to help others through innovation, we can sometimes be numb to human suffering. Hearing first-hand accounts of suffering from a lack of clean water helped me understand the importance of listening to multiple perspectives, especially those of marginalized groups.

As demonstrated by the above students from one module's reports and online discussion, it is clear that these projects were worthwhile and met the learning objectives of showing the intersection between engineering and social justice work.

Conclusions and Future Work

To reiterate, by incorporating social justice themed assignments into mechanical engineering design courses, we have the following three goals: one, engage students in the discovery that issues such as energy policy, sustainability, mining practices, bias in design, etc. are not separate from engineering practice. Two, disrupt the social/technical dualism present in engineering curriculum that often discourages engineering students from learning about and participating in social justice issues and discussions. And three, empower students to learn how they can work towards social justice in ways that support their professional development and career plans.

In the first phase of this project, we have described social justice modules that were incorporated into a thermal systems design course in Fall 2020, and one module from a mechanical systems design course that was implemented in Spring 2021. The module design—an iterative process that includes engineering analysis and reflection on the impacts—and the implementation of the modules in core mechanical engineering courses met our first goal of engaging students in these topics, and the second goal of showing the interconnectedness of engineering and social justice topics. In order to achieve our third goal of engaging students in the discovery of how they might work toward social justice within or beyond an engineering context, we feel it is important to understand our students' identities, as well as the communities and groups to which our students belong. Without this understanding, we may feel confused about why certain students embrace this type of curricular intervention while other students engage minimally or outright reject it. We also run the risk of focusing or emphasizing particular sociotechnical topics that don't reflect the current issues that interest and concern our students.

Related to all three goals, we know that engaging in this work requires far more than a personal passion for social justice. Although that is a commendable starting point, we also need to gain solid grounding in literature related to critical race theory, developing White racial literacy, social justice in engineering education, liberative pedagogy, and culturally-responsive teaching and mentoring. While we have developed a basic foundation in these theories and frameworks, we will complete a more extensive literature review starting in summer 2021, which will guide our future work. In parallel to a literature review, we will run four focus groups with students who completed the social justice modules in both design classes to gain an understanding of their identities and interests. We plan to refine our modules and implement them again in academic year 21/22. Additionally, we plan to assess the impact of the modules on students' attitudes and likelihood to continue social justice work in their engineering careers through the Social Justice Attitude [4] survey, coupled with focus groups and individual interviews.

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