Integrating Environmental Justice and Thermodynamics in an Engineering Education Design Project

ME-145 - Engineering Education Design

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Abstract:

This essay is an account of experiences and observations in the process of designing an engineering learning activity, incorporating best-practice learning strategies and additional recommendations from academics in the field of engineering education. In a small-group project setting, we incorporated learning strategies and educational practices to design 3 phases of an engineering learning experience: Developing a Learning Statement, creating an individual assessment evaluating performance to the learning statement, and designing a small-group learning task aimed to generate discussion and co-construction of knowledge. The disciplinary focus of the learning task is in thermodynamic heat exchanges and the social aspect rooted in the effects of pollution, namely thermal pollution, the heating of the world's waterways.

Introduction:

Engineering Education, within the field of engineering, is the study of how the practices of instruction and learning coincide in higher learning institutions to produce young engineers. These practices can be described according to varying scales of effectiveness, depending on the aim of the instruction. A professor lecturing, for example, can be described as passive learning, granted the student is listening and actively writing down lecture notes. A hands-on activity where the learner, having been presented a problem and tools to solve them, works independently or with group members can be best described as the application of knowledge. A discussion of ideas between peers in a problem-solving setting can lead to co-construction of knowledge - a state where learners interact their own understanding of a certain disciplinary topic with others' understanding to build a more comprehensive state of knowledge.

As illustrated above, there are myriad nuances in how the design and instruction of engineering learning activities can impact the effectiveness of the learning experience for engineering students. This course, ME-145, was taken during Spring 2021 - in the midst of the global SARS-COV2 pandemic - an event that radically interrupted many traditional practices - including a mandatory shift from in-person education to virtual instruction. Apart from resulting in a total educational loss of about 5 months of instruction - estimated to cost the U.S. an estimated $173 - $271 billion a year in earnings (Dorn, Mckinsey) - the shift to distance learning brought with it a shift in the style of instruction necessary for deep learning. Interpersonal communication with peers in breaks between lectures became a standard in in-person instruction, which would allow for the collective building of understanding of topics, which was no longer possible. As an engineering college student during this time, many of the shortcomings that virtual learning presented were experienced. However, creative methods of instruction were sometimes incorporated - illustrating the potential for what innovative, flexible, and engaging at distance learning could look like. By observing and studying both the shortcomings and successes of undergraduate engineering instruction - in-person and at-distance - we hoped to design a curriculum that combines the best learning practices with disciplinary content, rooted in the context of an issue relating to social justice. The disciplinary focus of the learning task is in thermodynamic heat exchangers and the social aspect is rooted in the effects of thermal pollution of waterways, developed in phases in a small-group project setting.

Background:

Throughout the course of ME-145, we read a series of short readings - the understanding of which were supplemented by peer-led, in-class discussions. In this section, a few of the academic articles were taken into particular consideration in the process of designing our engineering learning experience.

Schwartz, D. L., ABC's of How We Learn, Just in time Telling

Just in Time Telling is described by Schwartz Et al. as a constructivist teaching strategy in which students first experience a problem before hearing the solutions. When engaged by lecture, hands-on activities seemed to be the best in producing positive learning outcomes. Our biggest takeaway from this reading was the idea that, with JITT, the structure, timing, and sequence in which information is presented to a learner is important for the quality of learning during a given experience. Our design activity would take these considerations into account. This article informed some of our considerations into the design of our learning tasks to reflect these findings. Our main goal was to frame the learning experience as a problem to be solved, rather than a lecture and an associated problem. We thought of presenting a case study where the learners adopt hypothetical decision-making roles with different interests, along the way explaining a concept in thermodynamics - the solution to which would inform their decision in the hypothetical scenario.

Streveler, Learning Conceptual Knowledge in the Engineering Sciences

In this article, Streveler studies the idea of preconceived misconceptions and the barriers presented in overcoming these for an undergraduate engineering learner. One common area where these misconceptions can form is in distinguishing between relationships of physical quantities. Streveler focuses on the problems students have when first encountering forces imparted through velocity/acceleration in a physics class. The difficulty presented when relating the scientific definition vs. a definition from the lived experiences a student possesses. Additionally, this reading demonstrated how students' initial misconceptions can snowball as they move on to more advanced classes without necessarily having 'corrected' that misconception.

We discussed our experience in our introductory thermodynamics class - we were asked to solve all formulas and equations for joules, enthalpy, mass flow rate, etc. without meaningful real-world corollaries to relate the values to. We agreed that our past exposure to these values came in our undergraduate physics problem sets - but those are all highly constrained scenarios. We aimed to "demystify" these values by providing useful community-oriented contexts and different-subject-analogs to compare with.

Gupta - Integrating Macro-ethics Discussion in an Engineering Design Class

In his article, Gupta brought up the idea of the role of technological determinism in engineering decision-making & problem-solving. Gupta argues technological determinism stands in contrast to social constructivism - a more socially integrated decision-making process, where the needs and the feedback of the community are taken into careful consideration into every step of the design of an engineering solution.

We admired how Gupta illustrates this focus from technological determinism to social constructivism in his first-year introductory engineering lecture when he considers suggested solutions of a psychological nature on the same level of effectiveness as technical, technology-based solutions. Technological determinism is the dominant worldview in engineering classrooms and industries - the idea that technology can and will solve problems simply by the expansion of technology. However, in the example of giant tech corporations that provide services in exchange for user data (something that was not explicitly decided by the people) - we now see international governments speaking up to regulate tech corporations for these decisions made without the formalized input from a constituency. Social Constructivism, in contrast, would have involved the public in their decision-making from the beginning, seeking to consider all the possible stakeholders before making technological decisions.

Both these ideas illustrate the contrast between what the role of the engineer should be and how this role is incentivized to self-perpetuate in technological determinism (it is more profitable to make products and deal with the consequences after the fact).

Lesson Design Overview:

The design activity was crafted in different phases: defining the learning objective, crafting an individual assessment, building a small group learning task, and iterating on the previous steps using constructive feedback from peers and the course instructor. A few overarching themes from the course-assigned readings are discussed for informing much of our decision-making process for the design of this project. We hope to reproduce some of these themes in our solutions in our learning tasks. We have recognized that the practice of engineering does not happen in a vacuum, and must be rooted in harmony with the surrounding communities and environment.

In terms of personal challenges, Raul and I described our experience in our undergraduate thermodynamics as tough, unorganized (or maybe organized in a way not helpful for us), and rather insulated from the outside world. We took this topic on to explore the range of alternative lesson design possible within the discipline of thermodynamics, and hope aspects of which are adopted in future thermodynamic instruction.

Learning Objective:

In our initial meetings discussing the focus of the learning objective, we identified two promising ideas - thermodynamics of power generation and environmental pollution & injustice. At first, these two topics seemingly had many rich directions for us to take - presenting us with a sort of decision paralysis where it was difficult to choose one single issue to focus on. Among our options, we discussed possibly - lecturing briefly on thermodynamic cycles and the associated Pressure-Volume / Temperature-Entropy diagrams, or presenting a related textbook problem and asking learners to solve, then introducing a real-world scenario where they can give context to their thermodynamic analysis/answer.

We weren't completely sure on how we could connect thermodynamic concepts to topics relating to social justice, in a way such that the overall understanding of each isn't at a detriment. Perhaps not enough time was spent reviewing our disciplinary topic since we proceeded along with the project without checking for a deep formal understanding of the topic thermodynamic subject we wanted to cover. Not knowing what we were teaching was the likely reason for the difficulty in narrowing down our learning topic. The effects of this uncertainty are reflected in the Individual Assessment Design - given how broad the purview both were.

Individual Assessment:

We spent time grasping with ideas of what scientific or newspaper articles to provide, how the topic would be structured and introduced - i.e., lecturing, vs. giving resources with the expectation that students will engage with the material for self-learning. For this individual design, we focused on the idea of power generation and the various considerations that have to be taken into account for different stakeholders.

Two peer-student trials - Sophie and Olivia. The activity went well enough, which I attribute to our participants' outside knowledge (the participants did mention that without their outside knowledge they would've been able to respond to the activity, though perhaps not to the same degree of understanding). We discussed possibly presenting too much technical reading in our articles- while not necessarily being engaging enough for the construction of knowledge with the presented information. In doing so, we omitted some parts of our original learning statement- the 1st law of thermodynamics, and the use of the reference tables for fluid properties.

Small-Group Task:

Initially approaching this topic, we were not sure how to best engage students effectively, and we felt like a pivot away from the substance in the Individual Assessment was necessary. We adapted our activity to connect the ideas of power generation cycles and the environmental impact of the heating of waterways, known as thermal pollution, through exploring water usage in conventional power plants.

The challenges in this phase of our learning experience design included: finding a clear and relevant textbook problem, identifying a scenario tying the thermodynamic textbook problem with a pertinent environmental issue, and ensuring all resources are accessible to learners from all skill levels. In this section, we adapted the 5E Instructional model which encompasses the phases: Engage, Explore, Explain, Elaborate, and Evaluate (Bybee, R. 2014). In using this structured approach, we were better able to organize our information and opportunities for peer-to-peer discussion, hoping to bring about co-construction of knowledge. In presenting statistics and news articles relating to the thermal pollution of waterways from power plants, we were able to engage students in a problem to which they would apply thermodynamic principles to explore. As engaging as the topic of thermal pollution was, we felt the goal toward thermodynamics was lost. In future iterations, we would seek to reorganize our activity and shift away from word-heavy representations of our scenarios.

Cycle of Iteration: Small Group Task Design

For the cycle of iteration, we decided to focus on building upon our small group learning task. A few primary changes were made, primarily moving away from an interactive Google Docs sheet, to a structured Google Slides presentation along with an interactive whiteboard. In our move from Google Docs to Google Slides, we hoped to emphasize the importance of the content rather than highlighting unnecessary technical language in the activity design that would only serve to confuse, intimidate, and distract students from the disciplinary goal.

We believed this small-group activity held the most potential for constructive learning through the organized activity, presented and narrowed down external articles and videos, and structured discussion with their peers.

A practice trial was run with undergraduate Mechanical Engineering sophomores as the learning volunteers. Before beginning the lesson, we had a few minutes to introduce one another through ice breaker activities, which helped later in the activity in terms of participation. We recognized that these students were coming in on their own time for an opportunity for extra credit, and did not want to introduce additional stress, emphasizing our expectations were for them to simply actively participate to the best of their abilities.

After pivoting, we focused on reorganizing the phases of the learning activity to fit along with the 5E instructional model. This allowed us to better orient our activities and articles around our originally defined learning goals. We found that we covered our original targets: introducing a problem in the discipline of thermodynamics (condenser/heat exchanger), use of thermodynamic reference tables, and interpolation, all while rooted in an environmental justice lens.

Discussion:

Through our environmental justice angle, we hoped to recognize that the effects of pollution in the U.S. are disproportionately marked along socioeconomic lines. Connected the thermodynamic concept to the environment - we questioned whether we introduced enough information to consider social justice beyond direct environmental impact? We also wondered about the value of the disciplinary content in regards to enhancing understanding of social issues - i.e. does knowing how to calculate the rise in temperature of water passing through power plant cooling systems necessarily strengthen a learner's ability to understand greater environmental impacts? Would the discussion of marginalized people significantly enhance conceptual understanding?

Conclusion & Recommendations for Future Instructional Work:

Overall, it seems unlikely that a single workshop or learning activity can drastically shift any engineers' thinking to a more worldly point of view. However, we hope that some of the practices adopted here can work to supplement a young engineering learner's experiences. These recommendations for future instruction include: seeking a reduction in or modification (in terms of structure and timing) of how these problems are presented; developing a deep understanding of the real-world context of the problem; and emphasizing that the solution shouldn't be the end of interaction with the problem. Rather, the solution should be further evaluated with constructed, non-technical engineering knowledge in order to produce a full view of impact and solution. In all, there have to be ways to give learners more agency in terms of how they want to tackle a disciplinary subject, and more avenues for learners to interpret and give information towards finding a collective solution to a problem.

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