# Thermodynamics for Citizenship: Entrepreneurial Engineering through Project-based Learning

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## 1. Introduction

Project-based learning, also called problem-based learning, both abbreviated as PBL, originated in medical education (Burrows and Tamblyn, 1980) but found clear application in engineering education, especially engineering design (Dym et al., 2005). Today PBL is considered one of the high impact practices of teaching and learning across all disciplines (Kuh, 2008). Many undergraduate biological and agricultural engineering (BAE) programs feature service learning and project-based PBL opportunities, most frequently in first-year (cornerstone) and senior (capstone) design courses (Lima, 2013; Lima and Oakes, 2013). However, given the centrality of design in engineering practice and the challenge students encounter in trying to master design, it is valuable to scaffold the learning of these skills by including increasingly difficult design experiences during the intervening years between an initial first-year cornerstone design exposure and an open-ended senior capstone design experience (Dym et al., 2005, Wankat and Oreovicz, 2015). In addition, entrepreneurial minded learning (KEEN, 2019) is an approach to engineering education that encourages students to be curious about opportunities around themselves, see connections between disparate disciplines, and create value for themselves and others through their designs.

**Objective for this project.** Given that both collaborative project-based learning as well as service learning are considered high impact teaching methods (Kuh, 2008), there is potential benefit in exploring how PBL can be used in the second and third years of undergraduate biological and agricultural engineering (BAE) curricula, which are usually dominated by more theoretically focused engineering science courses. This paper describes one effort to introduce an entrepreneurial minded engineering project into a 3rd year BAE Thermodynamics course. Thermodynamics is a required course in 94% of BAE undergraduate programs (Kaleita and Raman, 2012). The goal for this project was to have the students apply their newly developed thermodynamics skills in a real-world setting, while developing an entrepreneurial engineering mindset and making a difference in peoples' lives.

## 2. Methods

**A compelling context.** The context for the project is food insecurity (Dubick et al., 2016). One problem at the local foodbank's mobile produce markets is that clients stand in the summer heat for hours waiting in line. Volunteers also experience heat stress helping pass out the food. Food is delivered via refrigerator truck, but once unloaded, often onto an empty blacktop parking lot, it can be a challenge to keep produce and the occasional perishable items at proper holding temperatures for the four to five-hour duration of the food distribution event. A solution is needed to keep people and produce cool. Stakeholders include clients, volunteers, the property owner, nearby property owners, the foodbank, and donors. Students discover the needs of these multiple stakeholders and propose multiple cooling device designs that could meet those needs.

**Thermodynamics Course Learning Outcomes.** Overall learning outcomes for the course are that upon successful completion of this course, each student would be able to:

1. Describe the role of energy in a global context
2. Locate and use data on thermodynamic properties of common gases and liquids
3. Perform thermodynamic analyses that follow a standardized format and include appropriate sketches, assumptions, and citations
4. Apply energy and entropy balances to problems involving heat and work
5. Apply 1st Law of Thermodynamics (Conservation of energy) to closed systems and open systems / control volumes
6. Apply 2nd Law of Thermodynamics (Restrictions on energy transfer) to closed systems and open systems / control volumes
7. Analyze and predict performance of engines, power plants, heat pumps, refrigerators, and air conditioners based on thermodynamic principles
8. Design a thermodynamic device that provides value to a range of users

This design project was most aligned with the last outcome, but individual assignments assessed student attainment of outcomes number 1, 3, and 7 as well as 8.

**Thermodynamics PBL assignments.** This project included six modules with six associated student deliverables spread over one semester:

- Concept map assignment exploring connections between energy and (a.) poverty, (b.) food production, processing, and distribution, or (c.) the environment (group assignment, each group picks one of the options)
- Preliminary documentation of clients' needs, characteristics, and perspectives to include discussion board participation, interviews, on-line and in-person research (individual assignment)
- Preliminary decision matrix memo documenting six different user perspectives (group assignment)
- Jigsaw assignment where team representatives investigate different cooling technologies and report back to their teams, (e.g., Refrigeration vapor-compression system, Evaporative cooling system, Thermo-acoustic cooling, and other creative designs) (group assignment)
- Conceptual design memo documenting three different designs to meet needs and create value (group assignment)
- Final decision matrix poster focusing on one user perspective from the three designs documented in the previous assignment (group gallery walk, stakeholder randomly assigned).

**Assessment and analysis methods.** The project was qualitatively assessed through analysis of reflections collected over two years from the faculty teaching the course, the graduate teaching assistant, a community volunteer who organizes mobile produce markets for the local foodbank, and undergraduate student participants. What follows is in their own words.

## 3. Results

**Faculty reflections.** I wanted to introduce more active learning to a course that is traditionally taught via lecture, and was encouraged by my participation in a KEEN-ICE short course to incorporate entrepreneurial minded learning as well. I like how adding this project to the course changed the focus of the students from memorizing equations and mastering generic calculation processes to thinking deeply about a very real problem in their community and considering how their engineering skills could help. We moved the learning of thermodynamic concepts from theory to practice, and opened some students' eyes to the needs of their neighbors. I presented this big audacious goal to the students early in semester, but made the early assignments concentrate on stakeholders and needs definitions, knowing it was too early in the course for the students to have the tools to actually perform the required engineering analysis and design. I was proud of the students, many of whom embraced this project. They took it seriously, and each year over a dozen volunteered their time to serve at one, two, or more of the mobile produce markets so they could see first-hand the problem they were trying to solve in class.

**Graduate Teaching Assistant reflections.** For some students, this was the first time that they had the opportunity to apply what they learned in class to a real-world engineering problem. I found that they appreciated this project's charitable context, as well as its engineering rigor. Students often approached me with questions regarding the outside temperature that they were designing for, or what target cooling temperature they should design for; they had not often been exposed to problems whose boundaries they themselves were responsible for delineating. For example, there would not have been a negative consequence to a team's grade if they had designed a system which worked within a relatively narrow temperature range, as long as their intended design conditions were congruent with their design.

The sense I got from the students in the class was that this project did not come across as an onerous add-on to their workload, but instead as an integration of what was learned during the course. I believe that there is utility to having a design project in the second and third years of one's college journey. Introductory cornerstone courses can be a whirlwind to still-adjusting freshmen, while capstone courses sometimes are the first time that students have leeway to define their own design conditions as well as identify constraints without much formal guidance. This project is situated well in the BAE curriculum to serve as an opportunity to get a glimpse of a capstone-caliber design challenge as well as often being the first time that a student who in the advanced stages of their undergraduate career gets to apply advanced theoretical principles in a real-world setting.

**Undergraduate student reflections.** This project was done twice, once in autumn of 2017 and once in 2018. Students were asked at the end of both semesters, as one of the questions in their final exam, what they gained from the class. One of the most common responses, and the expected result, was that the project helped cement their understanding of thermodynamic concepts. One student said, "after the application I had a much deeper understanding of vapor compression cycles and how they actually worked." Another common theme in student responses was how much the students valued the opportunity to participate in a project with a real-world application, since their projects had the potential to get pitched to the Mid-Ohio Food Bank.

Surprisingly, some of the responses focused more on the humanitarian aspect of the project, with responses such as, “I now see how much help is needed and would like to spend my summer volunteering when I have more time” and “I found out about a problem that I didn't know existed. These types of experiences are mind blowing and eye opening.” Some found the emphasis on an entrepreneurial mindset useful, “I gained insight on… the range of users/clients/shareholders you have to go to in order to see exactly what your project needs to accomplish/provide.” Overall students seemed to really enjoy the project and many took the opportunity to respond by just saying thank you to the instructional team for teaching the course and incorporating this project into it.

**Undergraduate co-author reflections.** The project originally seemed very overwhelming but began to seem more manageable during the first assignment. Early assignments did an excellent job of breaking down what was expected and focusing on the humanitarian part of the project, rather than actual calculations. This made it feel like I was doing something, even though I hadn’t yet learned enough thermodynamics to attempt finding refrigeration capacity or other technical parts of the project.

Before any of the assignments, the project was introduced with an interview of a community volunteer who works with the Mid-Ohio Food Bank, as well as some peers who had previously volunteered with the organization. This was a great motivator for working on the project because we were told that if our design worked and was reasonable, it would get pitched to the Food Bank’s board with the potential of actually being used. This experience also confirmed the project’s real-world implications, hearing about the community volunteer’s experience in the heat and helping people who would later eat food that had been sitting out for up to five hours.

A concept map on the intersections between energy and poverty continued the humanitarian engineering theme. This was a very broad assignment within a group based on our interests, another motivator, where we came up with ways in which people in poverty interact with energy, like transportation and education. My group took this on a global scale, doing some light Googling about the impact and usage of energy in developing countries versus developed, especially for those in poverty. The second assignment focused in a little more on the end goal of the project by considering who would be impacted by a device in the mobile food market, which begins to address the entrepreneurial objectives of the project. As someone without business experience, thinking about stakeholders was a new and useful task to think critically about different aspects the design would need to have in addition to functionality.

Humanitarian assignments then transitioned to more technical deliverables with the final three assignments, researching, designing, and presenting three possible refrigeration methods. The main research was done as a class, so three groups divided up and researched refrigeration vapor-compression system, evaporative cooling system, and then some other creative idea. This was done about a week after we learned about evaporative cooling systems and a little before we learned about vapor-compression systems which reinforced content lectured on in class. Doing the work as a group was a really useful way to get a lot of data without having to put in a ton of work on your own and then presenting it meant we could get feedback from our professor on things that were missed, so the learning became interactive rather than just a lecture. The design stage was certainly the most difficult, but also the most important for cementing our learning. Examples we had done in class were intended to line-up with this part of the project, even though we did not know that at the time we had done it. This made the technical calculations more of a review, rather than something we had to figure out from scratch, which was really helpful a week before the final exam.

**Community volunteer reflections.** My first Foodbank produce market was in early spring, over ten years ago. It was very cold, 18 degrees outside, and I arrived early to start getting set up. This was my first lead and I was nervous. As I pulled into the dark parking lot I saw a row of several cars. Then as I drove closer I saw walkers and several lumps on the ground. A group of elderly folks from a nearby low income senior housing facility had walked and/or driven here and were camping out in the cold to make sure they received food. Such was my introduction to food insecurity and MidOhio Foodbank produce markets in central Ohio.

Fast forward several years to a BAE thermodynamics course inspiring students with fresh ideas. Not only cold, but heat continued to work against people and food at produce markets. We can pass out blankets to ward off cold, but we had no way to keep people and produce cool in the summer heat. The students understood the needs of the various stakeholders and dug into the project. Gratefully, one of their options is indeed viable and may be used at future Produce Markets.

Even the design ideas that didn't pan out are worthwhile. The students had a chance to experience applied humanitarian engineering. What they do is crunch numbers. Why they do it is all heart for the betterment of others. I am grateful and impressed by these future engineers.

## 4. Concluding Recommendations

**Faculty Recommendations.** I recommend using PBL in teaching thermodynamics and other engineering science courses. I think the students learned more, and the course became more interesting and enjoyable for faculty and students alike. I recommend setting aside weekly in-class time for groups to work on the project and to keep students making progress, skipping content if necessary to make that time available. In this case, I deleted the topics of exergy and Rankine power cycle regeneration modifications from the course as I had taught it prior to adding this project. In the second year of implementation, I revised the order of topics so that refrigeration applications were covered before power applications, given that students' designs were to be about providing cooling. In future years, I would like to try to connect formally with the university's food pantry in addition to the MidOhio Foodbank. New for this year, I have hired an undergraduate during the following semester to help document, organize, and present top designs to Foodbank staff, laying the foundation for potentially moving the project from conceptual design only to prototype design / build / test.

**Graduate Teaching Assistant recommendations.** While having fluid teams at the beginning of the project was useful for idea generation and dissemination, it may be prudent to have fixed team members from the beginning of the semester so that a team dynamic can be achieved. This may help team members to distribute responsibilities and have more time at the end of the semester for their final design.

I recommend explicitly communicating that a team's design does not necessarily have to work at every possible temperature. This may result in multiple solutions which dovetail together to more effectively meet the range of cooling needs at the mobile food bank. For instance, one team may design a system which works well up to 100 degrees, and another team may have generated a solution which is only appropriate for 100 degrees or higher. These two systems would likely integrate nicely.

It would be interesting to integrate this design project into the capstone curriculum in some way. For example, one of the teams could be eligible to continue their design the following year as their capstone project. This could serve as an additional source of motivation to create designs which are well suited for prompt implementation.

Many of the positive comments about the project from the end of the semester were themed around having volunteered at the mobile food bank prior to beginning the design of their cooling method. This supports the idea that having additional opportunities to meet with the food bank members and other stakeholders would increase student engagement.

**Undergraduate student recommendations.** In addition to asking students what they gained from the course, they were also asked to reflect on what they gained from the course. The most common feedback recommendation was to assign teams as early as possible, both to have consistency in who they work with and to build a better team dynamic. There was also a desire to have some sort of hands-on aspect to the design project, "I think it would be cool to actually implement some of the design. If students were able to build the systems themselves it would provide some visual hands-on learning", "it would be cool to add in CAD to the project", and "A walk-through lab demonstrating the concepts related to the project where students collect experimental data for the project and analysis."

In 2017, some students asked to be given more in-class time while actually designing the project so they could ask Dr. Christy questions about what was expected and if they were on the right track. A student commented that "using the recitations to work together with your group was really helpful, more of that would be nice." This was implemented in 2018 and very well received by students but required incorporating example problems into the lecture.

Students from both 2017 and 2018 seemed to want more entrepreneurial and humanitarian involvement in the project. Multiple responses referenced some sort of cost analysis, " talk about how to do a cost analysis or what similar systems cost", "I would suggest adding a budget for designs ", and "I think it would be interesting to work this project into a lean sigma six white belt/green belt certification". While others asked for more involvement from the clients and volunteers, "Maybe bring in more people to talk to us… I would have had to skip class to go to a food bank site, so when the info came to me that was ideal" and "make sure at least one team member goes to the site."

**Undergraduate co-author recommendations.** The biggest difficulty in this project, as a student, is the time constraint near the end of the semester. This is partially due to the fact that teams were assigned so late, making it difficult to establish a concrete idea earlier in the semester. Having students complete the CATME survey (to randomly assign groups based on similar schedules and group dynamic) between assignments two and three would help fix this while still keeping some assignments individual. Using CATME to complete peer evaluations during and after the project would also be good to keep team members accountable and provide motivation to equally share the work.

Assigning the final deliverable earlier would also be useful, so students could begin planning the final product before in-class work days. That way time in class, with the professor to help with math or verification of ideas, is not spent brainstorming and designing more general parts of the final refrigeration device.

Another way to improve the project would be to offer two project ideas, addressing more student interests. Students in BAE have such varied interests including food, agricultural, biological, and ecological engineering. There are students who want to go to medical school, do research, work in industry, or work on family farms. Thus, for the context of the project to act as a motivator for all BAE students, it needs to apply to a variety of interests. This could be done by adding in a second aspect like designing a small on-site power plant, rather than only a refrigeration system. Hopefully, a power plant design would interest power & machinery agricultural engineers and possibly ecological engineers.

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