122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #12425

A Module to Introduce the Entrepreneurial Mindset into Thermodynamics - a Core Mechanical Engineering Course

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Abstract

The work proposed here consists of an educational module designed for thermodynamics (a core Mechanical Engineering course) that promotes entrepreneurially-minded problem-solving by linking the application of theory with economic and environmental costs. It was designed specifically to provide students with a hands-on approach to learning, while giving them exposure to integrating technical design and entrepreneurship. This was accomplished using an iterative design process of an electric-generating power plant that compared performance, cost, and environmental effects as key metrics. Additionally, a socio-political aspect is instilled through "governmental regulations" introduced throughout the course of the project. The module was implemented twice in Thermodynamics II. After each execution, a preliminary study was conducted via student surveys to determine if students considered the module a valuable addition to the course. These preliminary findings aimed at not only determining if the module should be continued in the future, but also at evaluating if the module resulted in: (1) increased student engagement and interest in thermodynamics, (2) increased learning effectiveness, (3) skills gained to help students integrate technical solutions with market interest, and (4) additional skills gained to help students develop the entrepreneurial mindset. Preliminary findings conclude that students perceive this module to be a great tool for not only improving learning effectiveness and engagement, but also for stimulating the entrepreneurial mindset. Future work will evaluate the developed module using quantitative data from bi-weekly progress reports, final project proposal, final presentation, team evaluation, and student surveys to validate these preliminary findings.

1. Introduction

Part of the key tenant of engineering education is to provide the skills necessary to develop novel technical solutions to problems. Investigations into the most effective pedagogies that accomplish this have been a focal point among institutions for years. However, if the U.S. is to maintain its economic leadership position, innovation is the key, and engineering education must be adjusted to incorporate innovative thinking while emphasizing the need to maximize customer value[1]. This is especially important considering the evolution of a global marketplace.

Known effective pedagogies, such as active-learning or problem-based learning, have positively influenced engineering education. However, in "The Engineer of 2020: Visions of Engineering in the New Century," the National Academy of Engineering identified that engineering education is still deficient in meeting the challenges associated with preparing students to succeed in a global economy[1]. In other words, our current education practices lack instruction on how to incorporate the customers' needs into a technical solution. To accomplish this and ensure the U.S.'s economic competitiveness, known effective pedagogies must be integrated with an entrepreneurial mindset. This mindset will take engineering education beyond providing students just a technical background, but will develop innovative thinkers who consider the value to the customer in their solutions.

Although many colleges offer courses focusing on innovation and entrepreneurship, none have integrated these topics with thermodynamics, a core Mechanical Engineering course. Thermodynamics is used by engineers in their study and design of a wide variety of energy systems, such as jet engines or power plants. Also, thermodynamics is a course known to be problematic both in teaching and learning[2]. The author believes this is due to students' perception of thermodynamics as an abstract topic (i.e. they cannot see energy flow like a fluid, or a structure standing). Thus, students memorize equations and never truly understand what those equations mean or how to apply them[3].

Realizing this student perception, it was hypothesized that by coupling the entrepreneurial mindset with known effective pedagogies, students would gain a better understanding of thermodynamic concepts, while becoming better engineers. Therefore, a problem-based learning module was designed to make students think in terms of what the customer sees as value, and to shape the technical solution to maximize that value. A preliminary study was conducted to determine if integrating the entrepreneurial mindset into thermodynamics improved students' understanding of the technical content associated with the course and the ability to integrate customer value into a technical solution. It should be noted that this module is in no way intended to prepare entrepreneurs. The goal was to prepare entrepreneurially-minded engineers.

2. Common Problems in Teaching / Learning Thermodynamics

It is no secret that students have had difficulty with learning thermodynamics for decades. As a result, many researchers have written on the issue and proposed solutions to improve student learning. Normah Mulop *et al.* reviewed techniques by various researchers from the past few decades that were aimed at enhancing the teaching and learning of thermodynamics. Many researchers found that students faced difficulties in understanding basic concepts, such as entropy or the first law, and their use for concrete applications[4].

In addition to misconceptions regarding basic concepts, students also have trouble in actually solving thermodynamic problems. Often times they do not understand the problem statement or even know where to begin. These difficulties associated with problem-solving can result in further complications as problems become more complex. This especially becomes true when students attempt to solve common thermodynamic problems, such as a power plant, which involves the integration of numerous devices and processes. Students have a difficult time mapping the abstract, theoretical thermodynamic principles to the complex power plant operation, preventing them from being able to complete an analysis[2, 3]. One researcher found that even visiting a real power plant did not help the students' understanding. This was due to the huge size of the plant, which made it hard to conceptualize how the different cycles and components work together[4]. Unfortunately as a result, students are unable to apply thermodynamic concepts to real situations, hating the course and perceiving it to be impossibly difficult.

Due to these difficulties, various methods for enhancing the teaching and learning in thermodynamics have been tried over the past few decades. It is certain that when traditional teaching methods are used they are not effective in aiding students in the retention of thermodynamic knowledge[5]. However, simply implementing alternative teaching methods into the classroom, such as active or problem-based learning, does not ensure that student learning will be enhanced or they will become better engineers. An engineer's job does not end with understanding how to apply theory. The job of an engineer is to provide a technical solution that maximizes the customer's value. These pedagogies lack the instruction for students to accomplish this, which is where the entrepreneurial mindset comes in.

3. What is the Entrepreneurial Mindset?

The goal of this course module is to integrate the entrepreneurial mindset into thermodynamics, a core Mechanical Engineering course. So what exactly is the entrepreneurial mindset then? Robert Kern[6], the founder of the Kern Family Foundation, explains the entrepreneurial mindset as, "An entrepreneurial mindset is our whole outlook on life, a curiosity level that leads us to understand what is taking place outside of the world we're living in—because ideas can come from anywhere. This curiosity that characterizes the mindset also tells us that life has to become a continuous learning process, and if people are not willing to commit themselves to a continuous learning program, either formal or informal, then they will be left behind. The world's changing too fast and it's a continuous challenge. There's something new to be learned every day. All of this put together wraps itself up to developing an entrepreneurial spirit."

Since this early description of what an entrepreneurial mindset encompasses, key attributes characteristic of an entrepreneurial engineer have been specifically defined. These attributes and corresponding skills are outlined in Table 1[6, 7].

These defining characteristics of an entrepreneurially-minded engineer were adopted for this course module because of their wide acceptance and detailed description. Of these characteristics, the following were a focus for this course module: *Curiosity*, *Creating Value*, *Engineering Thought and Action*, *Collaboration*, *Communication*, and *Character*.

Table 1: Attributes of an entrepreneurial mindset[6, 7]

Attribute	Skills
Curiosity	• Demonstrate curiosity about our changing world
Connections	• Integrate information from many sources to gain insight
Creating Value	• Identify unexpected opportunities to create extraordinary value for the customer • Persist through and learn from failure to learn what is needed to succeed
Engineering Thought and Action	• Apply critical and creative thinking to ambiguous problems • Apply system thinking to complex problems • Evaluate technical feasibility and economic drivers • Examine societal and individual needs
Collaboration	• Effectively collaborate in a team setting
Communication	• Construct and effectively communicate engineering solutions in economic terms • Substantiate data with facts
Character	• Effectively manage projects • Discern and pursue ethical practices

4. Thermodynamic Course Module

4.1 Overview

Students tackle an iterative, team-based design problem, where they are small start-up companies competing to build an electric-generating power plant. The project provides students not only with the understanding of how to apply electric-generating power plant theory, but also how design is integrated with, and influenced by, economic, socio-political, and environmental factors. These are all factors the entrepreneurially-minded engineer must be aware of, and keep in mind, throughout their career.

4.2 Details

The work proposed here consists of an educational module designed for thermodynamics (a core Mechanical Engineering course) that promotes entrepreneurially-minded problem-solving by linking the application of theory with economic and environmental costs. It was designed specifically to provide students with a hands-on approach to learning, while giving them exposure to integrating technical design and entrepreneurship. This was accomplished using an iterative design process of an electric-generating power plant that compared performance, cost, and environmental effects as key metrics. Additionally, a socio-political aspect is instilled through "governmental regulations" introduced throughout the course of the project. Figure 1 illustrates this complex, iterative design process.

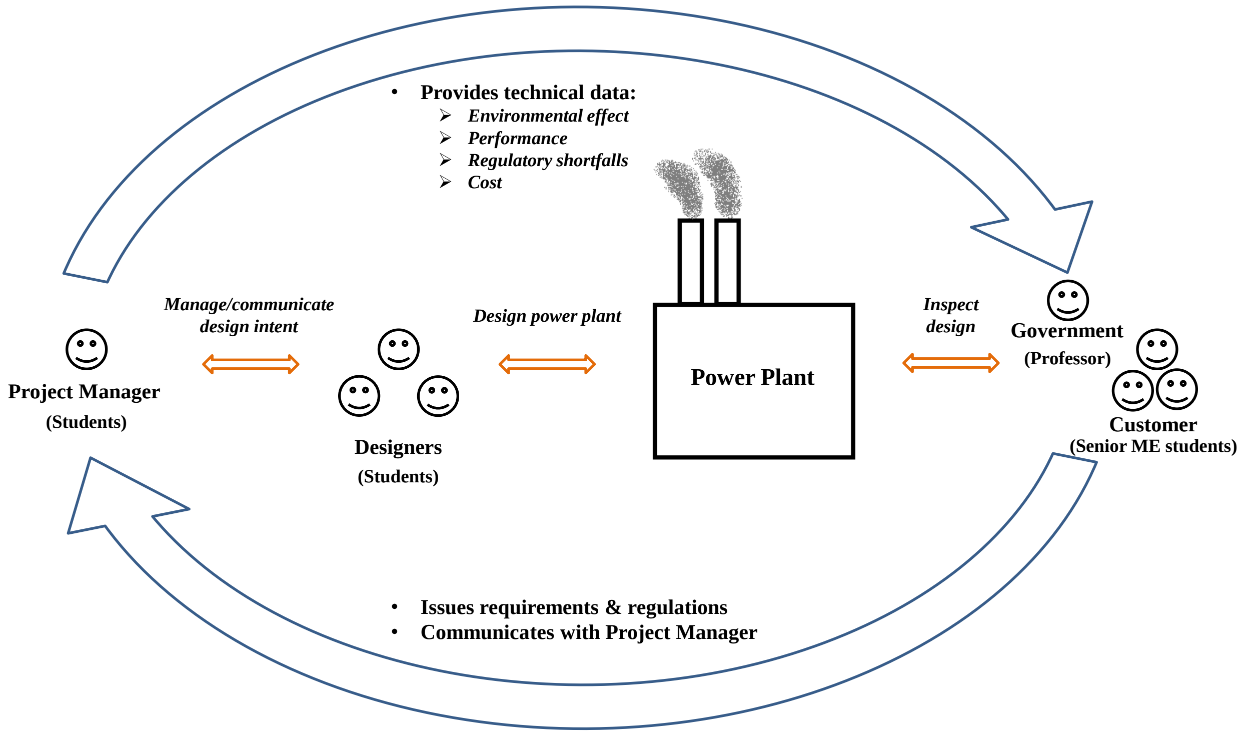

Figure 1: Course module's iterative design process

The project starts by the students dividing themselves into teams of four, where each team functions as a small start-up company. Each person within the group chooses a role to play within their company: project manager, financial analyst, public relations, or system integrator. To succeed in the project students will be responsible for fulfilling their role within the team, completing their commitments in a timely manner.

Each start-up company, using different fuel types (fossil fuel, nuclear, alternative energy), is charged with the task of designing and analyzing an electric-generating power plant. Starting with a basic vapor power plant cycle analysis, the objective of each team is to maximize the customer's value.

For this module, the customer's value is defined via cost, performance, and environmental impact. Cost is measured in terms of two categories, one the initial capital required to build the plant and two, the operating cost represented in Watson/kWh (note Watson is the currency for this module). Performance is measured in terms of system efficiency and total output power. Environmental impact is measured in terms of two categories; one is what method students choose to cool their plant (cooling tower or river) and two, their pre-defined fuel source.

Governmental regulations are imposed throughout the project to force students to go through multiple design iterations. Typically these regulations are based upon a customer value such as environmental impact or performance. An example regulation would be a monthly fine for any company choosing to cool with a river due to the negative environmental impact.

After formation, each company is given an initial budget to use in the selection of components for their design. An example of the different components for selection is shown in Figure 2. Teams must choose between components differing in cost and efficiency when developing their technical solution to maximize value.

Teams can earn more Watsons throughout the course of the project by completing assignments, doing well on assignments, or even doing research into new and innovative technologies used in existing electric-generating power plants. An example of a Watson given to students for completing an assignment is shown in Figure 3.

			Max Operational Range	
Name	**Cost (Watsons)**	**Efficiency**	**Pressure (kPa)**	**Temperature (°C)**
Boiler I	50,000	-	1000	179
Boiler II	105,000	-	8000	295
Boiler X	700,000	-	20,000	500
Turbine I	100,000	0.61	1200	200
Turbine II	250,000	0.47	21,000	500
Turbine X	400,000	0.83	8000	300
Condenser I	65,000	-	10	45.81
Condenser II	80,000	-	7.5	40.29
Condenser X	95,000	-	4	28.96
Pump I	80,000	0.75	1200	190
Pump II	65,000	0.68	21,000	370
Pump X	100,000	0.83	8000	300
Electric Generator I	150,000	0.85	-	-
Electric Generator II	400,000	0.98	-	-
Combustor	100,000	0.75	-	-
Isolated Reactor Building	800,000	0.95	-	-
Solar Receivers	300,000	0.15	-	-
Maximum Mass Flow Rate in All Devices				
1000	gallons/min			

Cooling Type	Cost (Watsons)	Maximum Flow Rate (gallons/min)	Inlet Temperature (°F)	Outlet Temperature (°F)	Environmental Fine
River	0	12,000	46	80	20,000 Watsons/month
Cooling tower	80,000	10,000	50	65	500 Watsons/month

Plant Type	Energy Source	Cost	Source/Leadtime
Fossil Fuel	Coal	65 Watsons/ton	USA-Appalachia/days-week
	Petrol	4 Watsons/gallon	USA-Gulf Coast/weeks
	Natural Gas	5 Watsons/thousand ft^3	USA-Gulf Coast/weeks
Nuclear	Uranium 235	63 Watsons/kg	Canada/years
Alternative Energy	Solar	-	Sun/8 minutes
	Wind	-	Variable

Plant Type	Energy Source	Ec	Environmental Fine
Fossil Fuel	Coal	25,000,000 Btu/ton	20,000 Watsons/month
	Petrol	125,000 Btu/gal	11,000 Watsons/month
	Natural Gas	1030 Btu/ft^3	10,000 Watsons/month
Nuclear	Uranium 235	500,000 MJ/kg	7,500 Watsons/month 50,000 Watsons/ton per week for storage of spent Uranium
Alternative Energy	Solar	3000 kW-hr	0
	Wind	177,000 kW-hr	0

Figure 2: Example of components for selection

Figure 3: Budget earned by students for assignment completion

With their starting budget in hand, students start investigating existing electric-generating vapor power plants from both an engineering aspect and in terms of societal/governmental needs. They are reminded to keep in mind who their customer is (senior Mechanical Engineering students and professor) and that the government (professor) will be imposing regulations throughout the course of the project.

Students then apply their knowledge of undergraduate thermodynamics to develop appropriate design metrics for their electric-generating vapor power plants, with the goal in mind to integrate their technical solution with the customer's needs. Students must be able to successfully integrate their technical solutions with economics, resulting in a product that is both cost efficient (meets customer value) and functional.

Students are required to present their technical engineering solutions with initial and operating costs to the customer, where they receive customer feedback to implement in the next design round. This communication occurs bi-weekly in the form of written reports and meetings.

This complex project was designed to be multi-dimensional (considers technical feasibility, economic, and societal factors) to force students to go through several design iterations. As new information is provided (i.e. customer feedback or legislation), students must perform an iterative analysis. This increases the difficulty of the project and encourages students to think creatively, learning from previous failures.

4.3 Learning Outcomes

This module was designed around *three main learning outcomes* associated with an iterative, team-based thermodynamic design problem. While these outcomes are outlined below, they were not assessed quantitatively as this was a preliminary study to determine if the module would be positively received by students. Future work will look at assessing the learning outcomes in detail.

A. Students will be able to apply thermodynamic principles to a multi-dimensional problem and generate technical solutions that maximize customer value.

1. Students start the project by investigating existing vapor power plants from both an engineering aspect and in terms of societal/governmental needs.
2. Students apply their knowledge of undergraduate thermodynamics to develop appropriate design metrics for vapor power plant operation.
3. Students will be able to successfully integrate their technical solutions with economics, resulting in a product that is both cost efficient (meets customer value) and functional.

This relates to the following characteristics and skills of an entrepreneurially-minded engineer: *exercise curiosity about the surrounding world* (by investigating current power plants) and *define problems, opportunities, and solutions in terms of value creation* (by integrating technical solution with customer need), *apply systems thinking to complex problems* (results from using a complex thermal system) and *examine technical feasibility, economic drivers, and societal/individual needs* (by requiring a cost effective and functional solution).

B. Students will develop the ability to effectively communicate, both written and orally, with their team members and the customer.

1. Students conduct the project in teams.
2. To succeed, students need to fulfill commitments to their peers and the customer in a timely manner.
3. Students are required to present their engineering solutions in economic terms to the customer, where they receive customer feedback to implement in the next design round. This communication occurs bi-weekly in the form of written reports and meetings.

This relates to the following characteristics and skills of an entrepreneurially-minded engineer: *collaborate in a team setting* and *understand the motivations and perspectives of the stakeholders* (design must meet customer's needs), *communicate engineering solutions in economic terms* (integrating technical solution with customer value), and *substantiate claims with data and facts.*

C. Students will develop the skills to carry out an iterative design process.

1. This complex project was designed to be multi-dimensional (considers technical feasibility, economic, and societal factors) to force students to go through several design processes. As new information is provided (i.e. customer feedback or legislation), students must perform an iterative analysis. This increases the difficulty of the project and encourages students to think creatively, learning from previous failures.

This relates to the following characteristics and skills of an entrepreneurially-minded engineer: *persist through and learn from failure*; *demonstrate resourcefulness;* and *anticipate technical developments by interpreting surrounding societal and economic trends* (all a direct result of iterative process with customer feedback).

4.4 Assessment and Evaluation

The course module was implemented into the Thermodynamics II course (ME 304) during the 2012-2013 (36 students) and 2013-2014 (66 students) academic years at Western New England University. After each execution, a preliminary study was conducted via student surveys to determine if students considered the module a valuable addition to the course. These preliminary findings aimed at not only determining if the module should be continued in the future, but also at evaluating if the module resulted in: (1) increased student engagement and interest in thermodynamics, (2) increased learning effectiveness, (3) skills gained to help students integrate technical solutions with market interest, and (4) additional skills gained to help students develop the entrepreneurial mindset.

The preliminary study used a survey where questions were written in the form of statements or questions and students were asked their level of agreement on a 7 point Likert scale between 1 (strongly disagree) and 7 (strongly agree). It is noted that as this is a preliminary assessment the questions were not peer reviewed. However, they were based on other peer reviewed published papers[8, 9]. Future work will include an expert review of survey questions. The survey was administered at the end of the semester, upon completion of the project. To date, the preliminary study consists of two administrations of the survey to purely see if the project was (1) enjoyable to the students and (2) increased the entrepreneurial mindset. From the survey data it is clear that this course module improves students' views of their learning effectiveness, introduces them to the entrepreneurial mindset, and improves student engagement.

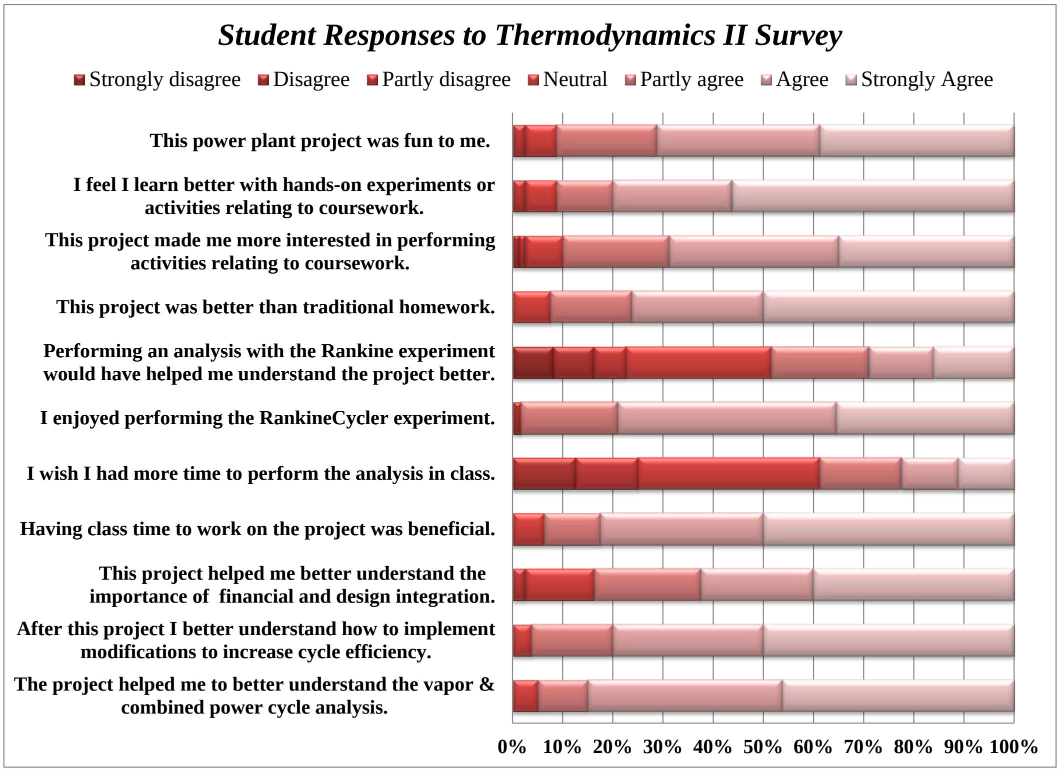

Figure 4: Results from student surveys

Conclusions made from the preliminary study were as follows:

- Students enjoyed the power plant course module;
- The project increased students' interest in the coursework;
- Students views of their understanding of basic concepts were improved;
- Students felt that the time allotted in class to conduct the project was adequate and beneficial;
- The project helped students understand the importance of financial considerations in design.

5. Conclusions and Future Work

This paper described the author's early efforts to develop a course module for integrating the entrepreneurial mindset into thermodynamics. This course module provides students not only with the understanding of how to apply electric-generating power plant theory, but also how design is integrated with, and influenced by, economic, socio-political, and environmental factors. All factors which are important to an entrepreneurially-minded engineer.

To date the author has implemented the project into her course twice and plans to conduct a more in-depth study in the future. Future work will consist of administering a pre- and post-survey, once at the beginning of the semester and then at the end, to gauge improvement in student learning of basic thermodynamic concepts and integration of the entrepreneurial mindset. Future work will also evaluate the developed module using quantitative data from bi-weekly progress reports, final project proposal, final presentation, team evaluation, and student surveys to validate preliminary findings. Statistics regarding reliability will be developed as the study is continued.

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