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Design of a Power Plant: Tailoring a Low-Risk, Low Budget, Student Design Project to Get the Most Out of Students

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Abstract

One of the goals of an engineering education is to teach students to design. Ideally, professors will find a way to introduce design projects alongside teaching the core curriculum. Textbook problems help lead into this by asking students to analyze or determine the capabilities of various components or systems. An excellent example of this is the second semester of the two semester Thermodynamics course series which typically focuses on various power cycles. While the real-world applications of these cycles are frequently alluded to, they are not always directly discussed. This proved to be an excellent opportunity to reinforce and practice the students' design skills. This was accomplished while giving students an in-depth understanding of the potential cycles used for power generation. For this assignment, students were tasked with designing a small-scale powerplant capable of providing the university with 12 MW of power. The deliverables for this project included both a written report and an oral presentation. Restrictions included that all component capabilities must really exist. Therefore, students were required to research the components and efficiencies used in modern powerplants. Students were also given extra points for achieving the highest thermal efficiency in their class. This helped identify one of the shortcomings in the balance of research versus design. Students would initially blindly copy the most efficient power plants in the world, without considering the fact that they were producing several hundred times the required amount of electricity. This project has been given over a period of five years, with slight variations in how the requirements were specified to the students. These differences that might seem minor from the outside, significantly impacted how the students researched the project and designed their final solution. As a multifaceted design project this assignment was also used to help assess the junior level students' progress towards meeting the ABET program outcomes.

Introduction

Engineers seek to design new things. To help train upcoming engineers to successfully accomplish this, engineering faculty are always looking for new ways to invigorate their students and let them see how the material they are learning in class will be applied to their future careers, as discussed by Svensson [1]. While taking an idea from initial concept to a finished working prototype is ultimately the goal, this is not always practical or feasible. This would require integrating material learned in most of the courses in the engineering curriculum to fully accomplish. This culmination of material is most frequently seen in a senior capstone course.

This leads to the use of paper-only design projects. While less exciting these projects are useful for focusing on only the material of interest in specific classes. This focused learning allows instructors to assess the student learning and application of only the material taught in the current class, and not their ability to combine the knowledge of material they have learned in multiple classes. This single class focused assessment is a necessity of the formative assessment of the ABET program objectives [2] that all engineering programs must meet. All mechanical engineering students are required to take some form of thermodynamics, either a one semester course or a two semester series, starting in either the sophomore or junior year, which makes it an excellent opportunity for a formative assessment of these outcomes.

One of the ways engineering faculty achieve these common goals is to share what they are doing in the classroom. The study of Vigeant et al. [3] focused on how thermodynamics is taught with a focus on chemical engineering majors, therefore this work was less focused on the power cycles that are common to thermodynamics courses for mechanical engineers. Chidthachack et al. [4] found that project-based learning allowed students to learn more than they would in a traditional classroom setting. Koen [5] argues the importance of teaching design to engineering students as a learned behavior. The study of Dym et al. [6] highlighted some of the challenges of teaching design to students. The study of Griffin et al. [7], looked at the impact of both group size and project length, however this study looked at senior design projects, where the length varied from one to two semesters as opposed to projects given as part of a single class.

In thermodynamics courses specifically, projects have been introduced to help enhance student learning of various concepts. Students tend to view thermodynamics as a difficult course and Dukhan et al. [8] examined some of the underlying causes that lead to this perception. Similarly, Carvell [9] noted, that students struggled to move on from just analyzing single components to studying full systems. In order to help students visualize this transition, Morgan [10] introduced a project where students not only toured the university powerplant but completed design alterations on the system. This allowed the students to understand how adjusting individual components impacted the overall system. However, it appears that in this project the parameters of the Rankine cycle that were adjusted were specified to the students.

This paper begins with a discussion of the previous experience the students had throughout the curriculum, and particularly in thermodynamics. This will be followed by a detailed discussion of the assignment as presented to the students. Next will be a discussion of how the students interpreted and completed the assignment. The paper concludes with a section discussing how the assignment fits into the overall learning pedagogy, including lessons learned and scalability.

Previous Experience

Throughout the curriculum students are assigned homework problems, typically from a textbook, that supplement the material being taught in class. However, these problems typically have the students evaluate systems that have already been designed without thought of improvement.

Thermodynamics is one of the cornerstones of any mechanical engineering program, which is taught as either a one- or two-semester series starting either the spring semester of the sophomore year or fall-semester of the junior year. The first semester introduces the concepts of the first, and second law of thermodynamics and applies these concepts to basic components, such as nozzles, diffusers, compressors, and turbines, with very little discussion, if any, regarding how these components might actually be used. The second semester primarily focuses on thermodynamic cycles. These include gas power cycles, vapor-compression cycles, and refrigeration cycles. Hopefully at this point, the students begin to see how all of the components they previously learned about can be tied together.

This opens an opportunity for students to design. The Rankine cycle, the basic cycle behind most steam powerplants, is an ideal candidate for this paper-based design project. This is due, in no small part, to the fact that the course textbook, Çengel et al [11], dedicates over half a chapter to various improvements that can be implemented to improve the overall efficiency of this cycle. The introduction and discussion of these power cycles rely heavily on the use of temperature versus entropy diagrams (T-s) which clearly show the process as the working fluid moves from state to state. A T-s diagram of a simple ideal Rankine Cycle is shown in Figure 1.

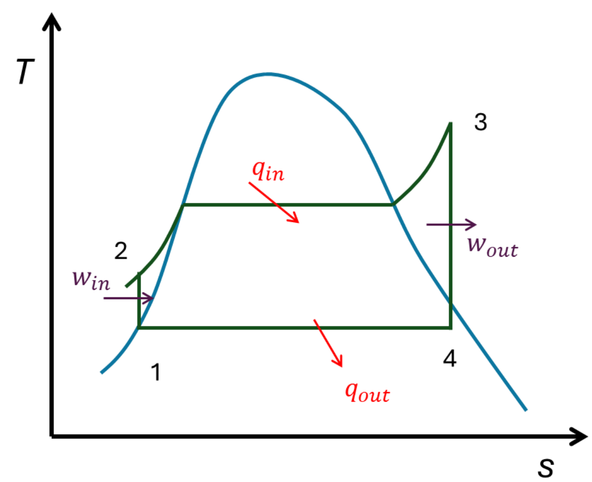

Figure 1. T-s diagram of a generic simple, ideal Rankine Cycle.

Assignment

Students were assigned the task of designing a new powerplant for the university. This powerplant was required to produce a minimum 12-MW of power. Due to metallurgical constraints students were limited to a maximum temperature of 620 ℃, unless they could prove their components could withstand a higher temperature. All components used had to be grounded in reality (isentropic efficiencies had be based on what real powerplants were currently using). Since this was solely a paper design assignment, the budget for this plant was assumed to be unlimited. Students were asked to provide at least a general idea of the size and footprint of their plant as well as possible locations for it to be built. Adding a flare of competition to the project an additional 10 points was awarded to the student(s) who designed the most efficient cycle each year. Students were also required to take the paper to the university student writing center. The goal of this appointment was to help the students with the overall quality of their writing. Most students used their appointment for help with overall structure, formatting and citations. This project was worth 10% of the student's overall grade in the class.

The deliverables for this project included a written report and an oral presentation. The written report was worth 80% of the grade while the oral presentation was worth 20%. The expected length of the paper was four to five pages including all necessary graphs, figures, and equations. The target length for the oral presentation was fifteen minutes. The first three iterations of this project were given as an individual assignment, while the last two iterations students were allowed to work in teams of two to three. This assignment was presented to the students during the seventh week of a sixteen-week semester with final presentations during the final week. When the project was assigned, class lectures were in the middle of covering potential modifications to the Rankine Cycle.

Student Execution

Research and written report

The general intent was for the students to at a minimum to use one of the example problems in the textbook [11], and improve on it. Students who only copied a simple Rankine Cycle with no improvements would receive a minimally passing grade as this would indicate no design considerations.

This proved not to be a major concern, as the students eagerly competed to develop the best cycle. The students demonstrated their research skills by seeking out a variety of sources which helped them make informed decisions as they completed their designs. While most of the sources the students cited were data sheets from manufactures, some students included peer-reviewed (or comparable) publications as well. One student used the work of Abdalla et al. [12] as an initial guide and scaled the cycle down. Another student used the work of Ganapathy [13], to help understand how to implement a steam generator into their cycle.

One of the biggest surprises was the student interpretation of the phrase, “components must actually exist” included in the assignment. This was intended for students to use as a restriction on component limitations. Instead, students became too focused on finding exact components to use and copying the most efficient powerplants in the world. Unfortunately, they forgot to then scale these plants down to only meet the required power production. This led to some students designing plants capable of producing almost 700 MW of power vastly exceeding what was required. To counter this massive overproduction students in subsequent years were required to develop a plan for any excess power generated.

The method of improving the basic Rankine cycle that was predominantly chosen by the students was implementing a combined gas-vapor cycle. This method was chosen by over half of the students. In contrast the addition of a feedwater heater was only chosen by three students or teams of students.

As can be seen in Figure 2, below, most students were able to achieve a cycle efficiency between 50 and 60 percent. The students who provided minimal improvements to the basic cycles as seen in the textbook achieved an efficiency of around 32.3%, whereas the maximum efficiency a student has presented exceeded 63%.

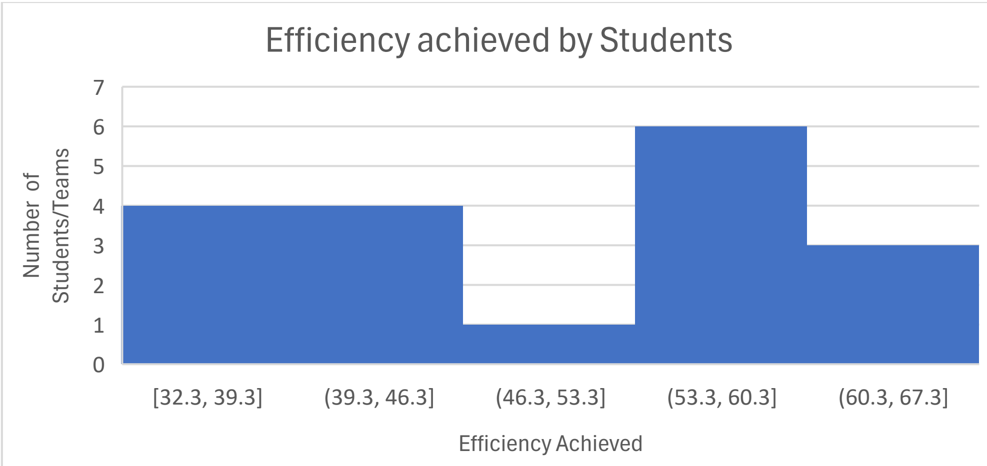

Figure 2: Breakdown of Powerplant efficiency achieved by number of students

Oral Presentation

The students had the opportunity to practice their oral communication skills, part of ABET outcome #3, when they presented their designs to the class. This is clearly an area where students need more practice. Some students were able to fill the allotted time of fifteen minutes and provide all required information and were able to answer questions as asked. Others gave very short presentations that were less than five minutes in length. Slide craft is an area that also stands out as a student weakness. While these students are juniors, and not yet prepared for a final assessment in senior design, it shows that oral communication skills are an area that needs to be addressed throughout the curriculum.

Learning Pedagogy

Pedagogically this assignment would fall into a partial design category. This is because it only requires a design and not a fabricated prototype. Therefore, it requires zero additional resources, such as a machine shop. While faculty were available to answer questions and provide guidance when asked, it was the students' responsibility to seek out any assistance they felt they needed. As would be expected some students eagerly asked questions to improve their project and overall learning, while others did not. Library resources were also available to the students.

This project was designed with the ABET learning outcomes in mind, particularly the first three outcomes as stated below [2]:

1) *An ability to identify, formulate, and solve complex engineering problems by applying principes of engineering, science and mathematics*

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*
3) *An ability to communicate with a range of audiences.*

The first two outcomes are examined based on how they approached the problem. Simply copying a problem from the textbook and presenting it as a possible solution to "design a powerplant" would constitute a novice level understanding. While this would still require the students to possess a basic understanding of the fundamental laws and mathematical equations, it would not require any additional thought or research. However, if the students were able to adjust their initial design with modifications such as: raise the boiler pressure, reduce the condenser pressure add a reheat process, add a feedwater heater, or consider a combined cycle, then they would move toward demonstrating a mastery of the material.

The level at which the students were required to discuss the needs specifically mentioned in outcome 2, was intentionally left vague. Focusing too much time on these topics, such as health, safety and environmental factors, could deviate too much from the primary focus, the thermodynamic cycle behind a powerplant, of the project. Students who mentioned these topics, even in passing, in their written report, demonstrated a more complex understanding of the problem. During the oral presentations students were questioned on some of these topics, especially when they discussed the desired location to build the powerplant. This led to a discussion of how it would impact the environment and school community.

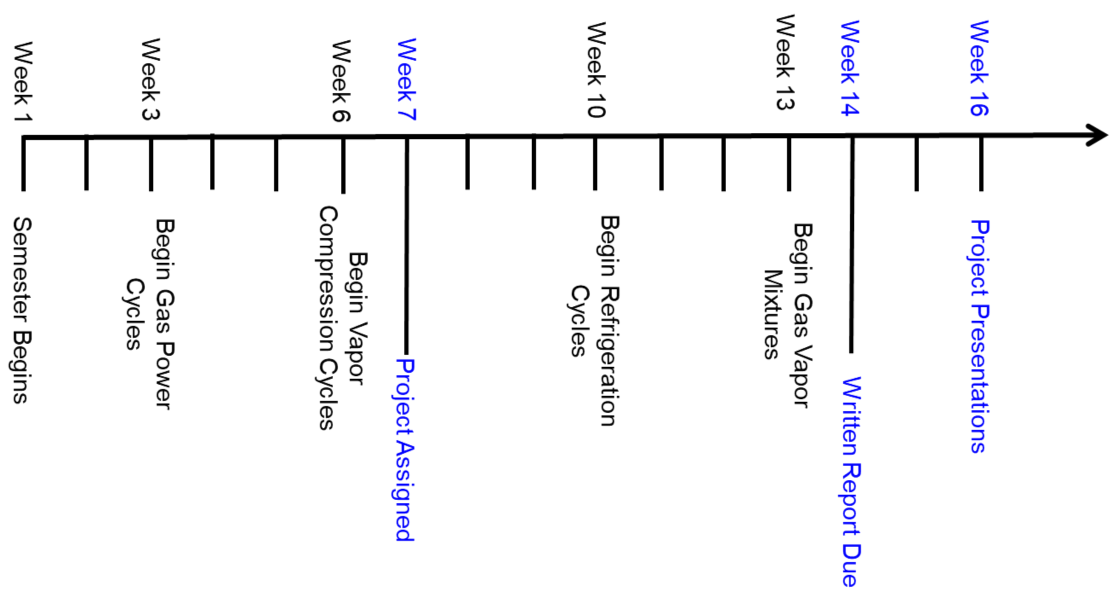

Figure 3: Semester timeline highlighting key points in the Thermodynamics II curriculum. This includes material covered in lecture and project assignment dates and due dates.

Outcome 3 is addressed via the written report and the oral presentation. As mentioned above students were required to take their papers to the university student writing center. While the tutors at the writing center are not engineers and are not expected to address any shortcomings dealing with the technical aspects of the paper, they are fully capable of assisting with grammatical and structuring questions the students may have. As noted by Davies et al. [14], engineering students have a tendency to struggle with writing, so any additional steps that can help should be taken. While the oral presentation is open to the general public, since it is given during class-time near the end of the semester it is expected that the audience will be a technical audience and they are instructed to prepare the presentation with that goal in mind.

As shown in Figure 3, above, this project was assigned to the students during the seventh week of a 16-week semester. This is at a point when the students have been introduced to enough information in the class to make the assignment meaningful, while still expecting them to be able to apply information taught in subsequent weeks. This also gave the students seven weeks to complete their assignment. While this amount of time could allow students to forget about the assignment until the last minute; students who embrace the project-based learning scenario will wisely use the time to conduct research and complete the project as intended.

Scalability

This project could easily be adapted to a university classroom setting of any size. While individual assignments allow for individual assessments of each student it is understood that in large classrooms this could become overly burdensome on the professor. Teams on the other hand allow students to share ideas and work together to develop a more perfect solution. This project has currently been assigned individually on three occasions, and to teams of two to three students once. Therefore, there is currently not enough information to determine if allowing the students to form teams produces better results. It is well documented that the ideal team size is no more than five students [7], [15], [16], [17], [18]. Therefore, a class of 100 students would require splitting into at least twenty teams.

Conclusions

This project has been an overwhelming success, and it will be continued. One of the beauties of this project is that is zero cost. Since it is a pencil and paper project the students are not required to actually build anything. This allows the students more freedom to stretch the limits of design by what is theoretically possible. Most students take this opportunity to explore the options attempting different approaches to achieve a higher plant efficiency. This embodies the spirit of the complex engineering problems specified in the ABET student outcomes.

For this reason, this project is used as part of the formative assessment of multiple ABET student outcomes as they prepare for their senior design experience. The students are asked not only to develop an initial solution to a complex engineering problem, but to look for ways to improve it. The students are then required to practice their oral communication skills by presenting their designs to classmates and faculty.

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