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Revision of a Semester Course Project in Thermodynamics: Description, Impacts, and Student Impressions

Dr. John R. Reisel P.E., University of Wisconsin - Milwaukee

Dr. John R. Reisel is a Professor of Mechanical Engineering at the University of Wisconsin-Milwaukee (UWM). He conducts research in engineering education, energy utilization, combustion, and air pollution. He also serves as the Secretary of the University at UWM.

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Abstract

For many years, the author used a two-part group project in a second-semester Thermodynamics course to reinforce various concepts taught in the course. The first part of the project involved a team of students designing a modified Rankine cycle for a steam power plant. The design was subject to a set of given constraints, and the students had a goal of maximizing the efficiency of the cycle. Economic considerations were included in the project by assigning a cost to each potential addition and limiting the amount of money a group could spend on their design. Following completion of this portion of the project, students completed a second part of the project that involved designing a combustion process to supply the heat for their cycle.

The author modified the project to better incorporate economic decision-making and creativity into the design process. Rather than having a two-part project, the project is now done in a single submission. In the revised project, each team is tasked with assuming the role of consulting engineers being asked by a utility to upgrade an existing basic Rankine Cycle through a variety of potential modifications. Economic considerations now centered on students reducing the cost to produce the same amount of electricity by improving the efficiency of the cycle – thereby reducing the fuel costs associated with their design. Students were given capital and operating & maintenance (O&M) costs to use for each potential hardware improvement as well as fuel costs. The teams determined the pay-back time for the investments in capital improvements and then determined the future profitability of the plant in light of the increased O&M costs and the reduced fuel consumption costs. While still providing students with experience applying the thermodynamics principles of cycle analysis and combustion analysis learned in the course, this format was designed to give students a more realistic experience of what they may encounter as engineers in their future careers.

In this paper, both the original and revised versions of the course project are described in detail, and the pedagogical reasons for the change are presented. Observations on the impacts of the revised project on student performance are discussed. Finally, a student survey was conducted to gather information on the student perceptions of the revised project, and the results of this survey are presented.

Introduction

For many years, engineering education focused on preparing students to be competent technically upon graduation from undergraduate programs. But in more recent years, there has been a push to focus on student creativity and to develop entrepreneurial skills in the students. The thinking behind this shift includes that a company will benefit from their engineers being more willing to take risks and explore new directions. While still needing to be very capable with engineering analysis, a greater emphasis on engineering design could help newly-graduated engineers be more ready to face the challenges posed by complex problems with no simple solution.

To help build more entrepreneurial thinking and creativity into the students' education, the author has modified earlier design projects in two senior-level technical electives in the Mechanical Engineering Department at the University of Wisconsin-Milwaukee (UWM). One of these modified projects is described elsewhere.[1] The second modified project is in a second-semester Thermodynamics course, and is described in this paper.

The design project builds from the concept of project-based learning[2,3] which is not new, and exists in a wide variety of forms. Ulseth et al.[4] used projects that directly connect students to an industrial sponsor to work on a solution to a real-world problem faced by the sponsor. Torres and Sriraman[5] paired students with industrial partners to work on solving a real-world problem. Students analyzed the design of an actual disc brake system in work described by Nespoli et al.[6] Traditional engineering science courses have also used project-based learning to give the students more context for the material being covered.[7] Project-based learning can be used in introductory engineering courses as a means of exposing students to new ways of solving problems while still early in their engineering studies.[8,9] At an even earlier educational stage, Rehmat et al.[10] used project-based learning while introducing fourth grade students to engineering, finding many positive benefits of such an approach. The work benefited the students educationally, and also improved many students' attitudes towards engineering as a field of study. On the other end of the educational journey, Gray et al.[11] used a project-based learning approach to enhance a senior-year engineering course. They found that students gained much from the project-based learning approach, but that some students didn't take full advantage of the learning opportunities presented to them. It can also be noted that some of the softer skills for engineering students sought by ABET can also be learned through project-based learning.[7] These and many other previous efforts using project-based learning have shown the positive impact that such an approach can have on student learning, and that the approach can be successfully used in many environments. With this background to draw upon, project-based learning was used with confidence in this course. Revising the previous project to a project with more realistic elements should only add to the usefulness of project-based learning.

According to Pusca and Norwood,[12] creativity stems from curiosity and curiosity can take many forms. One of those forms is asking why something impacts a design in a particular way, and what changing that parameter may do to alter the outcome. First learning that the choice of an operating parameter impacts the outcome, and then wondering how changing that parameter changes the result is an important step for an engineer to take to becoming an innovator. Yet this is something that may not be learned by students when the focus of the students' classes is learning how to perform a particular calculation to solve a specific type of problem. Using project-based learning gives students the opportunity to ask questions about how one change may impact an entire design in an environment where such thinking is necessary. For example, if you ask students to find the power out of a turbine with given inlet and outlet conditions, the student likely only going to learn how to solve that specific problem. But if you ask the student to recommend an outlet pressure for that turbine from a range of possible pressures, with conflicting constraints placed on the choices, students will be directed towards a more curious approach in solving the problem and can learn skills that can then be used when approaching other open-ended problems. Eventually, this curiosity and decision-making can lead to engineers who are more willing to think how to create the most value in their designs. [13]

The primary goal behind the redesign of the design project in this second-semester Thermodynamics course was to encourage students to explore options and learn more about how different factors impact a Rankine cycle design. To better prepare students for work in their post-graduate careers, the project was framed in such a way that they needed to consider economic factors when deciding if a proposed modification to the original design made sense in practice. It was also desired to address some of the shortcomings with the design project used prior to the modification. Below, the old design project is described, the shortcomings of it are identified, and then the revised design project is discussed. Observations on the initial offerings of the revised project are presented, and that is followed by a presentation of the results of a student survey on the new project.

Description of the Thermodynamics Course

MechEng 402: Thermo-Fluid Engineering is a technical elective course taken by Mechanical Engineering undergraduate students nearing the end of their B.S. studies. It serves as a second undergraduate thermodynamics course. When offered, the course typically has between 25 and 40 students. The prerequisites for the course are the first courses in Fluid Mechanics and Heat Transfer; as the first Thermodynamics course is a prerequisite for the Heat Transfer course, it is not listed as a specific prerequisite for MechEng 402.

The course consists of three main topics: thermodynamic cycles, psychrometrics, and combustion. As a foundation to the second and third of these topics, a secondary topic of ideal gas mixtures is also covered. A detailed summary of the weekly topical coverage in a typical semester is provided in Table 1. The primary focus of attention for the section on thermodynamic cycles is the Rankine cycle. This covers the basic Rankine cycle, and adds superheat, reheat, and regenerative heating through both open and closed feedwater heaters to the cycle. The section on combustion covers several topics, including basic combustion chemistry and the calculation of the heat of reaction for combustion processes; it does not include detailed chemical modeling of combustion processes. As will be discussed later, the Rankine cycle and combustion topics are brought together in the assigned course project.

Table 1: Weekly Topical Coverage in MechEng 402: Thermo-Fluid Engineering

Week	Topics Covered
1, 2	Review of Basic Thermodynamics
3, 4	Rankine Cycle (with modifications)
5	Brayton Cycle
6	Otto Cycle and Diesel Cycle
7, 8	Refrigeration Cycles
9	Ideal Gas Mixtures
10, 11	Psychrometrics
12, 13, 14	Combustion
15	Chemical Equilibrium, Project Presentations

While the department maps this course as helping to fulfill several ABET student outcomes,[14] (student outcomes (1), (2), (3), (4), and (5)), the course is only marginally used in the formal assessment of how well the program fulfills these outcomes. This is because the department has chosen to focus most of its assessment activities on required courses taken by all the students in the program. As an elective course, MechEng 402 would not provide a representative measure of the achievement of student outcomes for the whole program. However, by being mapped to several outcomes, the course is recognized as contributing to the achievement of student outcomes by the students who take the course.

For many years, this course has had a design project which determines 15% of the course grade. As this is a multi-student team project, the contribution of the project score to the individual student's course grade is kept relatively low. The project has involved developing a Rankine Cycle powerplant cycle design, considering budgetary constraints, and designing a combustion process to provide heat to the cycle. After using a previous version of the project for approximately 10 years, the project was revised to incorporate a more realistic design experience intended to better prepare students for their future careers as engineers. The revisions were also made to address shortcomings of the previous project noted by the instructor. While a more realistic experience, the project is still simplified considerably from what a design team would face in a real-world project so that it can be completed as part of a semester's course work.

Description of the Previous Design Project Assignment

The previous design project used in the MechEng 402 involved a team of 2-3 students working on a two-part project. The first part of the project involved the students designing a Rankine power cycle with various modifications. This was assigned relatively early in the course (around Week 5) after the Rankine cycle material was covered in the class and was due approximately 5 weeks later. A week after the first part was submitted, the second part of the project was assigned. This part involved designing a combustion process to provide the heat needed for their Rankine cycle design. Students were to design the combustion process for their cycle, independent of whether their Rankine cycle was designed correctly; however, students could recalculate their cycle's heat requirement after learning of errors in their initial analysis if they chose to do so. Students typically had three weeks to complete the second part of the project. Each part of the project was submitted in a formal written report.

The portion of the project involving the Rankine cycle design included constraints on the allowable conditions of the working fluid (water). Constraints were also placed on the physical elements of the cycle to guide the students towards more realistic designs. To encourage the students to attempt more complicated designs, students were required to add components to the basic Rankine cycle. Each team had to "spend" between a minimum and a maximum amount of money on additional components, and each potential component (such as a feedwater heater or a reheater) was given a cost. The minimum amount of money that needed to be spent by a team was large enough that teams had to add at least two additional components (for example a superheater section for the steam generator and a closed feedwater heater). The maximum amount of money that could be spent was high enough to allow for quite elaborate designs involving several feedwater heaters, a superheater, and a reheater. How teams used these modifications was important, as bonus points were awarded to the teams with the highest efficiencies provided that the complete analysis of the cycle was done correctly. Adding more components increased the difficulty of completing the analysis without calculation errors, but also increased the likelihood of having the highest thermal efficiency in the class.

The second part of the project that involved the design of the combustion process for the cycle was much simpler in scope. Students could choose whatever fuel they wished to use, while being encouraged to use simple chemical models for their fuel (such as using CH_4 to model natural gas). Only a few constraints were given to the students, such as the inlet temperature of the fuel and the air, and designs could not violate the Second Law of Thermodynamics. Teams could also not propose a combustion product temperature above the adiabatic flame temperature of the mixture. If a team proposed a design that would result in a combustion product temperature lower than the maximum steam temperature, they were required to explain how this could be done in the steam generator. In their report, students needed to justify their choice of fuel considering cost, availability, and CO_2 emissions. Finally, students were asked to find a current price of the fuel and calculate the cost of the fuel needed to operate the powerplant for one day.

Observed Shortcomings of the Previous Project Assignment

The previous semester project in MechEng 402 allowed students to have an opportunity to work through a thermodynamics design project, and tailoring the amount of effort they wished to put into the project to their interest level and available time. In particular, students were able to put in more effort to make a more complicated design and potentially improve their chances of earning bonus points if they chose to do so, but they could also put in a relatively modest amount of work to accomplish the bare minimum of the project if that best fit their interest and situation. The teams were small, which should have made it relatively simple to find time to work together as a team.

The instructor was able to observe project submissions and the approach taken by students over several years of assigning this project, and several shortcomings were noted.

1) The general approach to adding components to the Basic Rankine cycle was rather unrealistic. The primary issue here is that there was no test placed on whether or not it made sense to add a component. Teams had to "spend" money for components given arbitrary prices, and there were no criteria applied to whether the design modification was sensible to use. While teams generally did not add components that did not improve the thermal efficiency of the cycle, fundamentally there was no reason not to do so if all the team was trying to do was spend a minimum amount of money with the simplest possible cycle modifications.

2) The connection between the two parts of the project was weak. Students only needed to use whatever value they calculated for a heat input requirement for the first part as the heat needed to be produced by the combustion in the second part. They were to provide a rationale for their choice of fuel, but the rationale didn't need to be well-connected to reality. While the second part was an open-ended design problem, it did not appear to

particularly help the students in their understanding of combustion and many teams put very little effort into it.

3) The small size of the teams limited the amount of learning that could be done by students learning from each other while working together. As a result, relatively simple errors were often missed by the students. Most semesters when the project was assigned, despite bonus points being available to the top three teams with correctly solved designs, there were unawarded bonus points due to fewer than three teams with errorless analyses.

4) Many times, the teams appeared to consist of individuals working on their own designs and then choosing the best efficiency from the individual designs, or in having one or two students work on Part 1, and another student work on Part 2. In other words, the teams were often not functioning as teams.

To address these shortcomings and to provide the students with a more realistic project experience that emphasizes adding value to a design, the design project was modified. The modifications primarily focused on the first two of these shortcomings, but the team size was also modified in an attempt to address the last two shortcomings.

Description of the New Design Project Assignment

The new design project continues the same concept of designing a combustion-based Rankine cycle for a powerplant, but changes the approach taken to improve the realism of the project. While still not exactly what students might face in their careers, the project does bring in more realistic elements to make the experience of working on the project potentially more useful.

The project teams now typically consist of four students. The scenario that the students are given is that they are a team of consulting engineers seeking business with a utility company which wants to upgrade an existing powerplant that employs a basic Rankine cycle (with a poor efficiency). The students are given details on the existing facility, including the thermodynamic states at the relevant points in the cycle, a value for the current amount of money spent on fuel each day, a value for the current operating and maintenance (O&M) costs, and the revenue from electricity sales. Students are then given information about 11 possible improvements that they can make to the cycle, each with a capital cost and an O&M cost.

It should be noted that all of the equipment costs are not meant to be exact, but are more realistic than what were used in the previous design project. By not being limited to using current exact prices, the values of the capital and O&M costs can be changed each semester so that students need to work with a new design project rather than simply finding an old project to submit as their own.

Students are also given 9 limitations that must be followed in their new design. These limitations include the maximum allowable temperatures and pressures for the cycle, a minimum allowed pressure, the total amount of power to be produced, and limitations on the combustion design. Students are also presented with a situation where the turbine's isentropic efficiency depends on the outlet state of the water. This is presented in a somewhat simplified manner (with the efficiency being based on the isentropic outlet state of the water rather than the actual outlet state) but gives the students an analysis challenge that they do not experience elsewhere in the course.

The student teams are tasked with proposing modifications to the current cycle to improve its thermal efficiency and the profitability of the plant. Therefore, they need to incorporate the concept of adding economic value to the design and making engineering judgements based on such economic factors. The student teams need to design the combustion process for using natural gas by choosing the air-fuel ratio, and the reactant and product temperatures. From this combustion process design, they can determine the fuel costs for their new cycle design. They are given the unlikely scenario that the utility will be paying for the plant's improvements from available cash and are told that the utility wants to see a payback time on the capital costs of 3 years or less. The students need to prepare a proposal to modify the powerplant cycle by considering whether the improvements they propose make economic sense to the company. They should determine whether the increased revenue from electricity sales (by decreasing the amount of fuel used, and therefore the cost of the fuel used) minus the extra O&M money spent allow for a rapid-enough payback of the capital costs incurred in their new design. Students are also asked to determine the additional profit achieved by their design at the 5-year and 10-year marks. To simulate presenting their proposed design to the utility company they are to submit a detailed written design report to the instructor and make a short oral presentation of their design to the class. Bonus points are still awarded for the top designs that were analyzed correctly and met the design constraints.

An additional feature was added to the project to enhance its realism. Twice during the semester, new or changed information was provided to the students on "change sheets". The types of changes included revisions in price, the inclusion of an additional design constraint, and changes to an existing constraint. This was done to reflect that information and requirements may change during the course of performing such a project while working as engineers.

This is now a single-part project, unlike the previous two-part project. This can lead to some problems for the students, as they do not learn the necessary aspects of combustion analysis until late in the semester. To address this, students are encouraged to start working on developing several possible cycle changes by the middle of the semester, with a focus on making significant improvements in the thermal efficiency of the cycle with each one. Then, once they have learned enough about combustion analysis to determine the amount of fuel they will need to buy to generate sufficient heat, they can include the economic analysis to complete their project.

Teamwork was promoted in this project by having the students evaluate their teammates at the end of the project. If the majority of teammates indicated that the performance of a member was poor, the student's grade was reduced significantly. While not a perfect way to encourage teamwork, this does offer students an incentive to work as a team rather than as individuals (or not working on the project at all).

Observations on the New Design Project Assignment

The first shortcoming of the previous project was addressed by creating a more realistic scenario for the new project than existed in the previous project. The set-up of the project is much closer to what students might experience once they become engineers, and the need to justify the economics of the changes also adds realism. The second shortcoming is now addressed by making a clear purpose for the combustion analysis: the combustion analysis is needed to calculate the economics of the project.

The third and fourth shortcomings of the previous project both involve teamwork issues. Adding another member to a typical team was one strategy to try to increase the amount of cross-learning that can occur while working on the project. Including the evaluation of teammates was intended to discourage students from not working with their teammates on the project. In the offerings of the new version of the project, teams have yet to successfully analyze a design correctly, with at least one small error being made by each team. However, this can be at least partially attributed to the added complexity of the project, rather than being an artifact of having an additional team member.

After several offerings of the project, the instructor is able to make some general observations. First, the student teams were able to successfully understand what they were expected to accomplish as a team of consulting engineers bidding on the project. This led to generally effective oral presentations of their proposed cycle design and a logical presentation of the economic aspects of their design. While some of the written reports could have been written more professionally, the reports generally met the expectations for format and content.

Second, as mentioned, so far none of the projects have been presenting designs without some analysis error. As these projects involve many parts and calculations, this is perhaps not surprising, albeit disappointing. Still, many projects contained only a small number of analysis errors, some of which are attributable to the students trying to apply the material while still taking the course in which they are learning the material.

Third, most student teams took an approach of having only a few modifications to the existing cycle, appearing to be trying to either minimize the effort they needed to put into the project or as a strategy to introduce fewer possibilities of making calculation mistakes (and thus having a better chance of earning bonus points.) For this second possibility, the drawback of this approach is that each mistake in a simpler design is more damaging to the grade, as there are fewer things done correctly due to the smaller number of calculations that are needed with simpler designs. It should be stressed that teams were not appearing to go with simpler designs because the economics didn’t dictate a more complex design. Teams were supposed to indicate in their report what other designs were considered, and teams that did attempt more complex designs were not indicating that these designs were not better economically. Rather, a more common explanation for not using a more complex design was that it was “too complicated” for them to analyze. To address this, a method of encouraging students to experiment with more components and a more complicated design is needed, so that fewer teams default to doing the minimum amount of work necessary to get an acceptable grade. To promote work on the project earlier in the semester, an instructor might require the teams to submit written progress reports over the duration of the project, or might schedule a meeting with each team to discuss their progress face-to-face. These approaches would provide the instructor with an opportunity to directly encourage the development of more complex designs.

Fourth, the use of evaluations of team members has mixed results. When a team consists of friends, there is a strong tendency for each team member to say that all of their partners were excellent – which is a doubtful evaluation considering the rather simple nature of many proposed designs and the number of errors made in the projects. However, the method did appear to be helpful for teams that were put together from the group of students who did not have people that they wanted to automatically work with on the project. This gave students in such groups an opportunity to point out a lack of effort by teammates, and this did happen with a few students each semester.

Lastly, the students would benefit from more instruction on project organization and management. To the instructor, it appeared that many if not most teams would work on the project either when all gathered together or would instead have each student go and work on a single design and then the team would choose which design was best. Neither of these methods is particularly efficient. The students were encouraged to develop a living project on-line so that students in the group could each contribute to it as they had time, with the team still getting together weekly to discuss where the project was at and what else could be done. However, this approach did not appear to be used by very many teams, which likely led to the more conservative designs submitted.

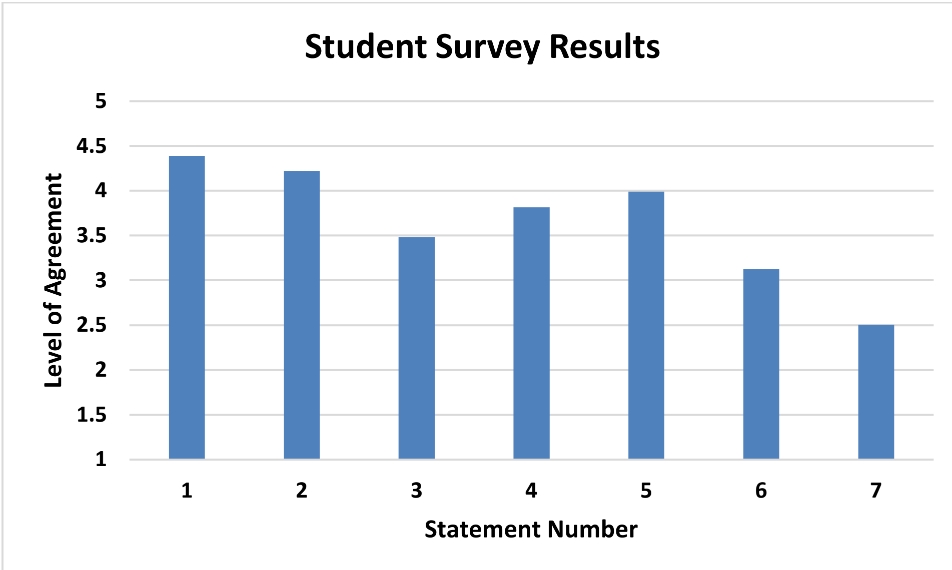
Student Survey Results

To gain an understanding of the students' views of the revised project, the students were asked to fill out a short survey on the new project in the first two semesters in which it was used. A 5-point Likert scale was used (1 – Strongly Disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, 5 – Strongly Agree) to allow students to indicate their level of agreement with the following seven statements:

S1: The project improved my understanding of the course material.
S2: The format of the project simulated a realistic professional engineering activity.
S3: My group worked on the project steadily through the semester.
S4: The project was more enjoyable than projects in other Mechanical Engineering courses.
S5: The project made me more aware of aspects of the engineering profession I may experience in the future than other projects have done.
S6: The project "change sheets" during the semester caused my team to redesign our system under development.
S7: My group would have benefitted from more instruction on how to function well in a team.

It is recognized that some of the statements may have been difficult for some students to assess – particularly statement 2. However, in the case of statement 2, many students taking the classes have had some experience working in an engineering environment and therefore would have had a basis from which to indicate their level of agreement with the statement.

Figure 1: Average scores of the level of agreement expressed by the students on the new project survey (n=90).



The survey results from the two semesters were very similar, which is reasonable considering that the project was presented in the same manner and the two groups of students should have a similar background and educational experience. Therefore, the results are presented as being the average of the 90 surveys returned (out of a possible 92 students who completed the project). The average scores on the level of agreement with each statement are given in Figure 1.

The survey results indicate that students were, in general, benefiting from the project and most felt that it was a positive educational experience. From Statement 1, the level of agreement indicates that most students found that the project improved their understanding of the course material. The results for Statement 2 indicate that most students found that the project was realistic in nature. Statements 4 and 5 asked the students to compare this project to other projects that the students had worked on in their engineering studies. While more students found the project more enjoyable than other projects than not, there is likely a need to find ways to make the project more enjoyable in general while retaining its rigor. Statement 5 indicates a good level of agreement that this project was making students more aware of what they may encounter in the future as engineers. It should be noted that if students were taking this course in their last semester as an undergraduate, they also were likely simultaneously taking their capstone design project course. By the nature of its projects, the capstone design project course should be providing students with even more insights into their future careers. Statements 3 and 6 relate to how the students approached the project during the semester, and the results from these statements raise concerns that students are putting the projects off until late in the semester. If that is the case, it helps explain the lack of success in producing a fully correct design analysis and the rather conservative approaches taken to the designs. The relatively low impact of the change sheets during the semester suggests a need to rethink how to better utilize that project feature. The results from statement 7 suggest that some students feel they could benefit from more discussion on how to work well in a team setting, but the majority of the class disagrees with that. As a result, a good approach may be to offer a supplemental session for students who would like more information on effective team practices, but not to use regular class time for such a discussion.

It is problematic to develop a quantified analysis of the impact of the project change on student success in the course. Direct comparisons of project grades will not work, as the rubrics used in assessing the projects naturally changed. As the project is submitted at the end of the semester, the only relevant exam to use for comparison is the final exam. While the final exam retains a similar format each semester, the problems change and the exam also covers topics that are not part of the project. With these considerations, a comparison of the average final exam grade for the first three semesters using the new project (140 students) and the last three semesters using the previous project (114 students) show that the average final exam grade increased 2 percentage points. An ANOVA analysis indicates that this is not a statistically significant increase; however, it is notable enough that the instructor will continue to monitor this in future offerings of the course.

Summary

In this paper, a revised semester project used in a second semester of Thermodynamics course was described in detail. Information was provided about the previous project used, and an explanation for how the revised project addressed the shortcomings of the previous project was provided. The revised project mimics placing the students into the role of a consulting team proposing power plant modifications to a utility company. The students base their recommendations on economic considerations. By changing costs, the project can be used each semester without the concern of students using solutions from previous semesters. A student survey indicated widespread agreement among the students that the project helped improve their understanding of the course material. However, instructor observations indicated that students often did not take full advantage of the educational opportunities available in the project as most groups kept their design proposals rather conservative in approach.

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