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Implementing Project Based System Analysis in Introductory Engineering Thermodynamics

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Abstract:

The following paper is an evidence-based practice paper. When first teaching introductory engineering thermodynamics, it was seen that the lowest scores in the semester occurred on questions regarding full thermodynamic system applications, such as power plants, internal combustion engines, and other similar systems. Typically, grades up to that point on homework assignments and exams were good, but dropped sharply with the system analysis. Even if the grades on individual component pieces were good, when combining them together, something was happening with the understanding or application. After several years of seeing this trend, a new method of teaching and learning for these systems was implemented. Instead of assigning homework problems, and making students solve different versions of systems, a team based project was used to apply the concepts of thermodynamic system analysis. During class periods, base systems of power plants and internal combustion engines were introduced. Students and faculty worked together and solved example problems for the base systems, so students had a beginning point and a basic solution to work from. The student groups then chose their project. The project consisted of choosing a basic system, and making at least two changes to the overall functioning of the system. Changes could be as simple as adding components, such as reheat cycles, to a power plant, or adding a nitrous boost to an internal combustion engine. Some changes students made were more complicated, for example changing the working fluid in a power plant to liquid salt instead of water. Students were asked to make the two changes, then perform full thermodynamic analysis, including first law, second law, and efficiency or coefficient of performance calculations, including for a range of input conditions. The groups then had to submit a full written report with results, and present their work either in class or at the annual university research symposium. The project has been implemented and part of the course for 4 years now, as much time as the course was taught without the project. On average, the students now score 15% higher on the same exam questions as they did without the project using traditional homework assignments.

Keywords: Thermodynamics, Project based learning, Project implementation

Introduction:

The following paper is an evidence-based practice paper. Eight years ago, the institution I teach at, Marian University in Indianapolis, Indiana, introduced a new course into the curriculum for engineering students. I was assigned to teach this new course, Engineering Thermodynamics. As I was preparing to teach this course, one thing I saw was the difficulties others had documented both in teaching and learning the subject matter [1],[2],[3],[4],[5]. I went into the course looking to see where any problems would occur.

For this thermodynamics course, the topics covered started with heat transfer and transfer mechanisms, then moved to the First and Second Laws of Thermodynamics, introducing steam tables along the way. Next, the class covered entropy and isentropic processes. While covering these topics, methods used included traditional lectures, in-class examples, homework assignments assigned from the textbook, and in-class group problem solving sessions. Three exams were given, and the class had a relatively high average for grades. After the last in semester exam, the final topics covered vapor power plants, the Rankine Cycle, and internal combustion engines. The topics were taught using the same methods as previous topics, and the practice problems on homework assignments and group sessions was similar.

In regards to vapor power plants, the standard base Rankine Cycle system, shown in Figure 1, was the first model introduced, and one example was done to solve this system in class. Next, we would cover the changes that could be made to this basic system, such as reheat, superheat, etc. For each change, we would solve one example problem for the system in class, and they would have one or two on a homework assignment.

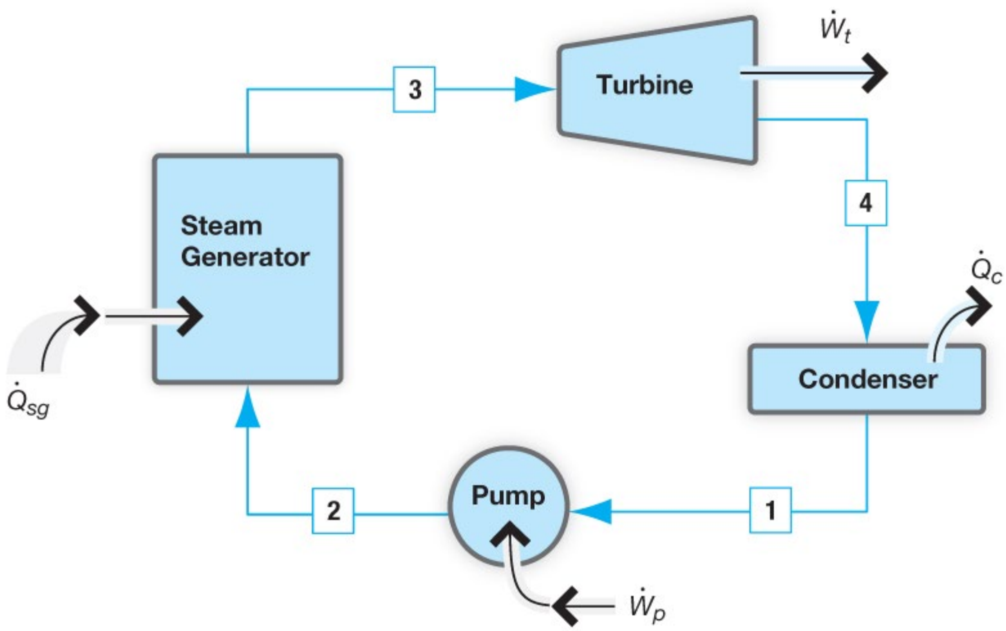

Figure 1: Standard Rankine Cycle Power Plant used in examples for class [6]

On the internal combustion engine, I would introduce the basic engine system, as shown in Figure 2. We covered the different methods of solving engine systems, including Otto, Diesel, and Dual cycles, and we would solve one example of each in class, with at least 1 on each being assigned on the homework.

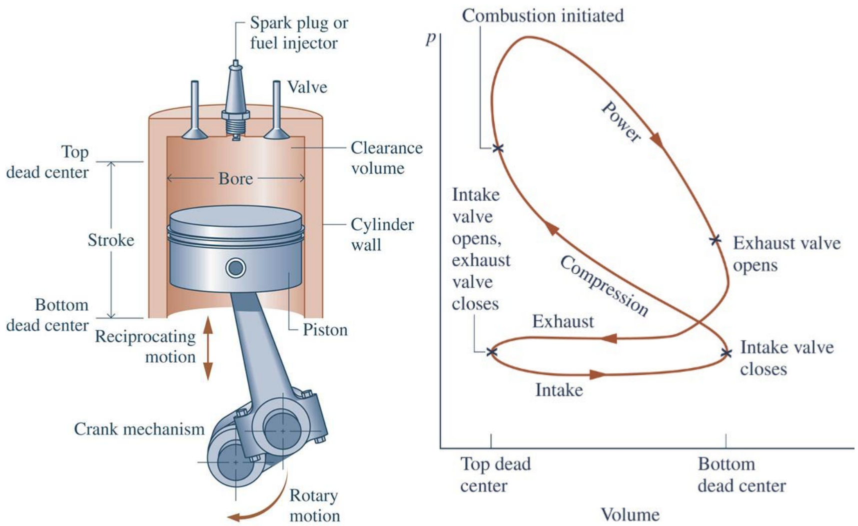

Figure 2: Standard piston cylinder engine and Otto Cycle diagram [7]

At this point, students were solving problems as groups, turning in homework assignments, and there was no sense of anything wrong. The final exam for this thermodynamics course was a cumulative final consisting of six questions. Four of the questions were review, from the earlier material and earlier exams. Two questions were based off the vapor power plants and internal combustion engines. On the final, one problem on each, using the basic systems, was given to the students. These problems are shown in Figure 3.

Problem 1 (40/200 points)

The boiler and condenser pressures of a Rankine cycle with steam as the working fluid are 60 bar and 0.06 bar, respectively. The cycle utilizes superheated vapor in the boiler at a temperature of 360 ^{o}C and saturated liquid leaves the condenser at a temperature of 36 ^{o}C. The condenser, in this application, only changes saturated vapor into saturated liquid. The steam flow rate is 18 kg/s. (If needed, use the enthalpy between the pump and boiler as 157.56 kJ/kg) Calculate (i) the power output of the turbine, (ii) the power input to the pump, and (iii) the thermal efficiency of the plant. (iv) Draw the system.

Problem 2 (40/200 points)

An Otto cycle with a compression ratio of 8 involves an isentropic compression process followed by heat addition to the max temperature of 1400 K followed by an isentropic expansion process to the initial volume of 0.861 m3/kg. A constant volume heat rejection process returns the air to the initial state of 100 kPa pressure and 300 K temperature.

(i) Find the thermal efficiency of the engine.

(ii) Find the heat added in kJ/kg of air assuming variable specific heat.

Figure 3: Final exam questions on engines and Rankine cycle power plants

During grading of the final exam, it was clear that two problems on the test were scoring low, the problems on power plant systems and internal combustion engines. The grades on the final exam were lower on average than the rest of the semester. Since there were noticeable differences, I looked at the average scores on the review questions as a whole, and the average score on the power plant and engine questions. The class average on the four review questions was an 86%. The average on the two other questions was a 57%. It was clear something was wrong, or the students didn't completely connect to these topics as well as they did the others. As I reviewed the course and looked at what other teachers had to say, I could see that this topic was one that typically was harder to teach and harder to grasp [8],[9],[10],[11],[12],[13].

Moving into the next year, and the second attempt at teaching this class, I came in with the knowledge of where the difficulty would lie. The beginning of the course proceeded in a similar manner to the year before, and the grades were good. When we got to power plants and engines, I decided to add more examples on the base systems, thinking students needed to see more. Since the previous year's exam was not returned, the same problems were used in the following years. After the final exam, it didn't seem to do much, as the scores were still very different, and the two questions on the base systems were still in the low 60% range.

At the conclusion of the course, I again reviewed other sources looking for ways to improve, but I also noticed something on student evaluations. Many of the students in this class stated that they felt the textbook and problems didn't do a good job on the final few topics. So for the third year of teaching the course, I changed the textbook. Over the next two years, with a new book and more examples on power plants and engines, I still did not see a change in the scores on those problems on the final exam. After four years, the overall average on the four review questions on the final was 81%, and the four year average on the power plant and engine problems was 63%.

After again reviewing the course, it was clear that I needed to try something new when teaching the power plant and engine topics. For the fifth year of the course, I cut back on the homework problems on the basic systems, assigning only two problems on basic power plants, and two problems on basic internal combustion engines. In place of the extra homework problems, students were assigned a project based on one of the two topics. Students worked in groups on the project and presented it at the end of the semester. The course has now been taught with the project for four years, and the average on the two questions on the final has increased 15%.

Methods:

The only difference for this class between the first four years and the following four years was the project. During the later four-year period, as mentioned above, the basic power plant and engine systems were the only ones extensively taught during class. The subsystems and changes were discussed, but no example problems were done in class. Instead, three or four examples on each of the basic systems were done. The homework assignments for this section consisted of only basic systems. Instead of covering extensively the different types of systems, students were asked to do this in a project.

Over the course of the eight years this course was taught, the student demographics in the class varied. This course is taken by all engineering majors at Marian University, so the majors vary as well. Of eighty-one total students in the class, fifty-one (63%) have been mechanical engineering majors, thirteen (16%) have been biomedical engineers, five (6%) have been electrical engineers, four (5%) each in computer engineering and engineering physics, and two (2.5%) each in motorsports engineering and energy engineering. Additionally, twenty-four students (29%) have been female. Sixty students (74%) have been scholarship student-athletes. The percentages held between the group without the project and group with the project, within 3%.

For the project, students are allowed to work in groups up to three students. They can choose the groups, and are asked to design a thermodynamic system using any components they want to use, and perform analysis on each component and the system in general to evaluate performance. The system has be something different from the base systems explained in class. They must change AT LEAST two components to one of the systems but can add as many as they would like. Changes to the basic system suggested include adding constant-pressure contraction to a diesel engine or adding a superheat system to the basic Rankine Cycle. Students could also choose to change the working fluid in the system or change basic parameters such as boiler pressure.

The project requires students to fully analyze the system they design. They are asked to pick reasonable values for the states of the system. For example, they are asked to not use the pressure of intake air for an engine as six atm; use standard one atm pressure, so that these are reasonable systems for analysis. Students are required to show all calculations and assumptions for the system, and define the pressure, temperature, specific enthalpy, specific internal energy, and specific volume at each state. They are asked to calculate the heat added, heat removed, power developed, and power input for each stage, and find the efficiency of their system. They are also required to prove that the system is thermodynamically possible using the First and Second Laws of Thermodynamics.

As part of the project, each group needs to create plots showing the efficiency of their system for varying input states, such as variable air temperature. Finally each group is asked to submit a full written report with a diagram of the system, as well as any calculations and plots as described above. They must also explain all the steps involved in the calculations, and detailed explanations of every step of their system, including changes they made.

At the end of the semester, each group must present their system to their classmates as a group oral presentation. During the presentation, each group is required to present the information, calculations, and results of their project. During this portion of the project, students are essentially teaching each other the material. Rather than working on their own on a homework problem with similar changes made to the base system, they are listening to detailed reports from fellow students of how the changes effect each system. Each group is required to walk through the steps and calculations, and all students end up seeing multiple systems explained to them by each other.

Each group is also given a chance to obtain extra credit for their project. In addition to the oral presentation on the project they give to the class, students are given the option to present the project as a poster at Marian's Undergraduate Research Symposium. This poster presentation is open not just to engineering students and faculty, but to all majors across all schools at the university. Students have given feedback that this interaction is helpful, as they often have to explain their systems and their projects to faculty from liberal arts departments who don't have much knowledge on the topic. The groups are teaching not only each other, but they are teaching people outside their area of study who have never been in this class or studied this material. The students have given feedback that this only helps more as it makes them learn the system more and requires them to be able to explain the details on what they have done,

Results:

Over the four years that the project has been a part of the course, the projects and changes made have been interesting and very different. Each year, the groups try to do something new, and something that interests them or relates to other work they are doing. One of the first projects submitted was a Rankine cycle that added a reheat element to it. The diagram of the system created by the students is shown in Figure 4. The second change to the base system the group made was to change the working fluid from water to lithium nitrate. At the time, two chemistry students were taking the course, and they were doing independent research with chemistry faculty using lithium nitrate, so they used the same material here. An interesting result they found was that they system didn't work well except for a small range of values, so they only got a single efficiency of their system at 42%, an increase from the standard system using their values with water, which had an efficiency of 23%.

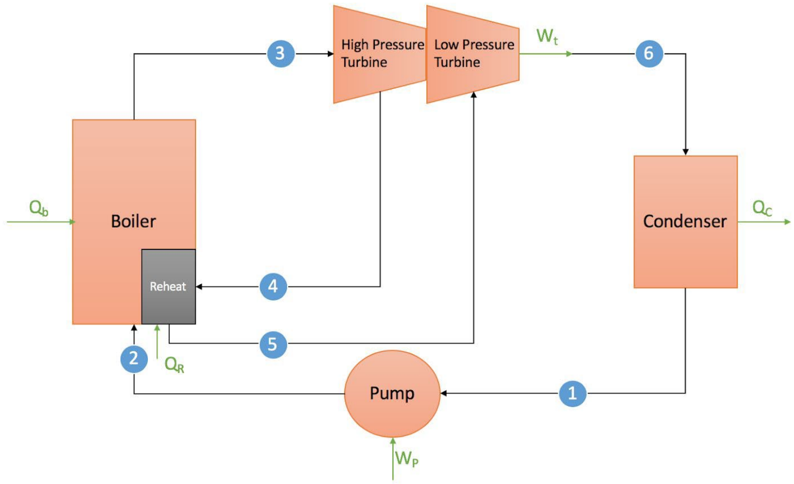

Figure 4: Designed system with ideal Rankine cycle with Reheat used as a model to evaluate using molten lithium nitrate as medium fluid

In the years since the first project, several groups have followed the same method of changing the working fluid, and each time they have chosen different fluids. One group followed a very similar model, adding reheat, but using potassium instead of water. The diagram for this system is seen in Figure 5. This group programmed code into MatLab to process their data and changes, and they found that the system is impossible. No matter the initial conditions, the group found potassium wouldn't work as the fluid in a Rankine cycle.

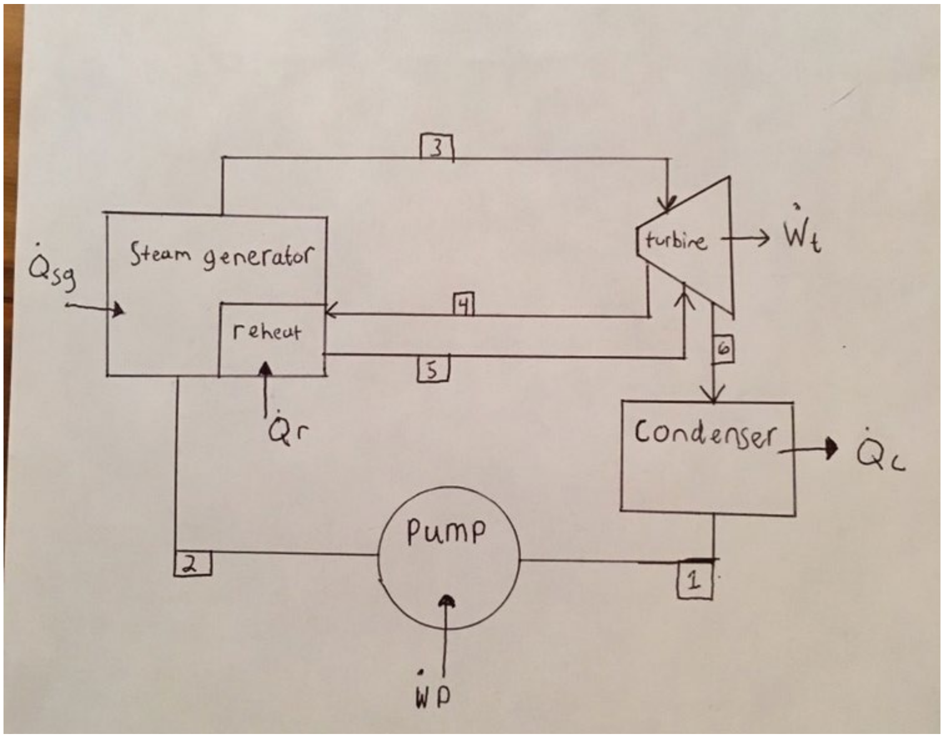

Figure 5: Rakine cycle with reheat using potassium as the working fluid

Another group changed the Rankine cycle fluid to ammonia and added a second pump to the system. Their diagram, along with a graph of the effects on the efficiency of the system is shown in Figure 6.

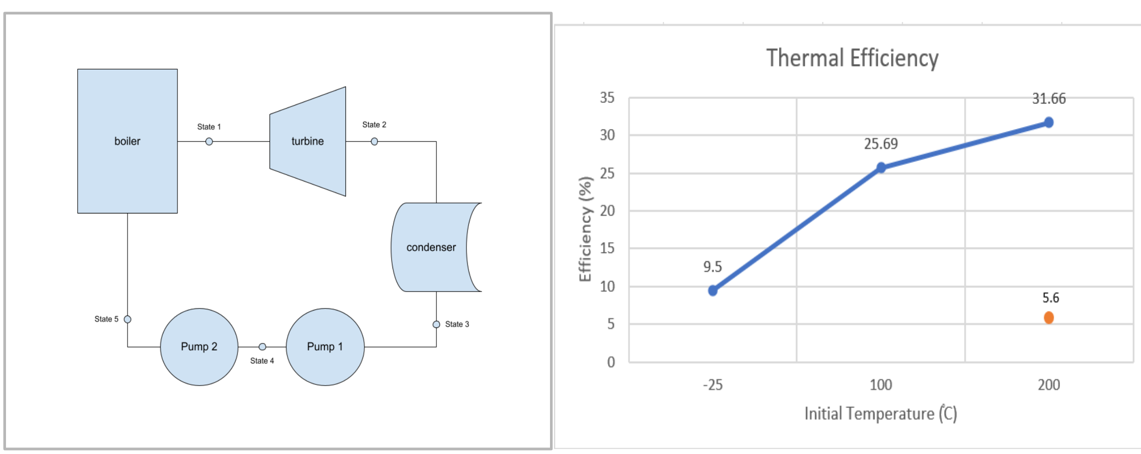

Figure 6: Rankine cycle using ammonia as working fluid with second pump

Other groups decided to make changes to the standard Otto cycle engine system. One group added an intercooling system and increased the compression ratio of the engine to 10, and saw an increase from 21% efficiency to 70% efficiency. Another group took the standard engine, and added a turbo system, while increasing the compression ratio, and analyzed using different fuels. Their hand drawn diagram, along with a graph of efficiency of the engine with different pressures and different fuels is shown in Figure 7.

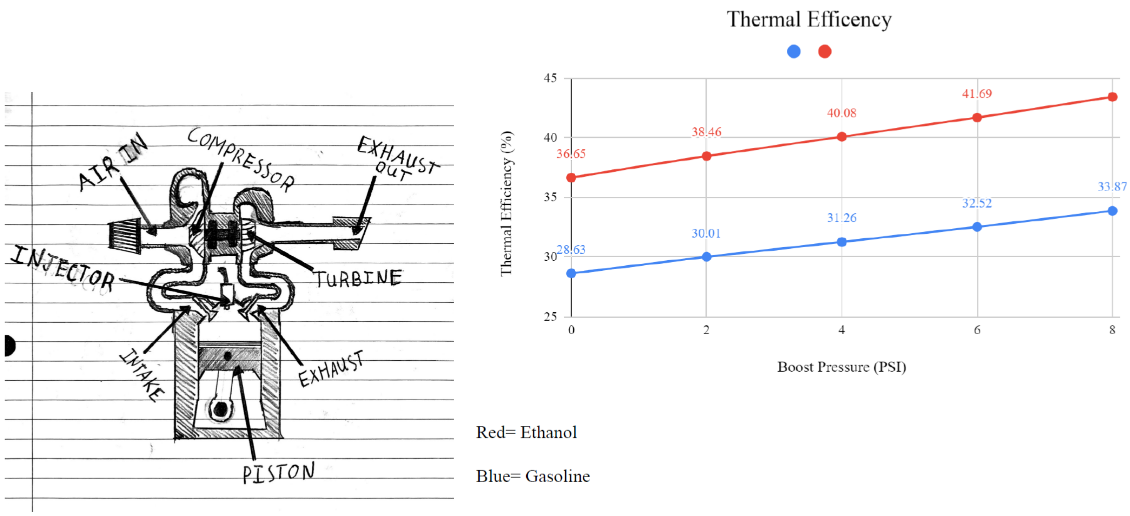

Figure 7: Engine with turbocharger and graph of efficiency changes.

Other groups have asked for permission to venture outside the standard systems we used in class. One group worked with a jet engine, and found the output work and output speed of the jet engine as the input velocity of air varied. Another group used a Brayton cycle refrigerator, using R134-a and varying condenser temperatures. They obtained a graph of the coefficient of performance based on the condenser temperature, and that is shown in Figure 8.

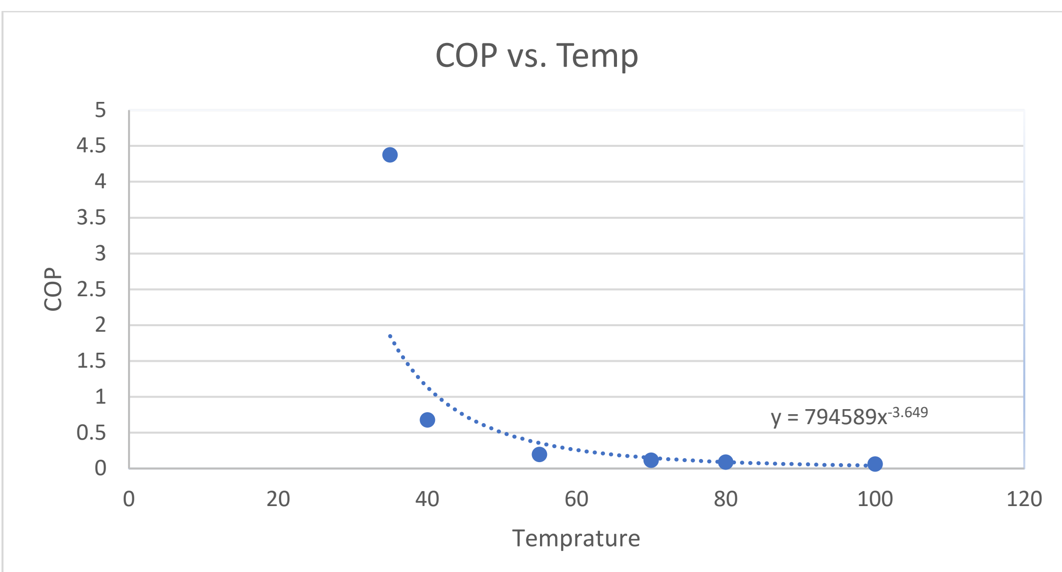

Figure 8: Graph of Coefficient of performance as a function of condenser temperature for a Brayton refrigeration cycle.

These projects are just some of the examples that students have turned in over the last four years. The key to the project was the effect it had on the final exam scores. The first year the project was introduced, the exact same two questions were used on the final exam. The average on these two questions jumped from a 63% the prior four years, to a 73% with the project. For one year, this could have been an outlier, but the trend continued, and actually got even better. The project has now been used the same number of years it has not been used, and Table 1 shows the data for these sets.

	Number of Years	Number of Students	Average Percent Score on Review Questions	Average Percent Score on Rankine Cycle and Engine Questions
Without Project	4	37	81	63
With Project	4	44	82	78

Table 1: Average scores on Final Exam questions based on project inclusion in course

As you can see in the Table 1, the average score on the Rankine cycle and Engine problems increased from 63% in the four years without the project, to a 78% in the four years with the project, a 15% increase in overall score. The yearly scores have also showed a steady increase year-over-year. As I can provide students example projects and they see what has been done, they can then apply that to their own project, and the projects become more in depth. The more detailed and complicated the projects, the better they seem to do. Figure 9 shows a graph of the average scores on the Rankine cycle and engine problems year-to-year, and the increase while using the project can be clearly seen. Also in Figure 9 is the average scores over the four years without the project, and the scores jump around and there is not a set pattern.

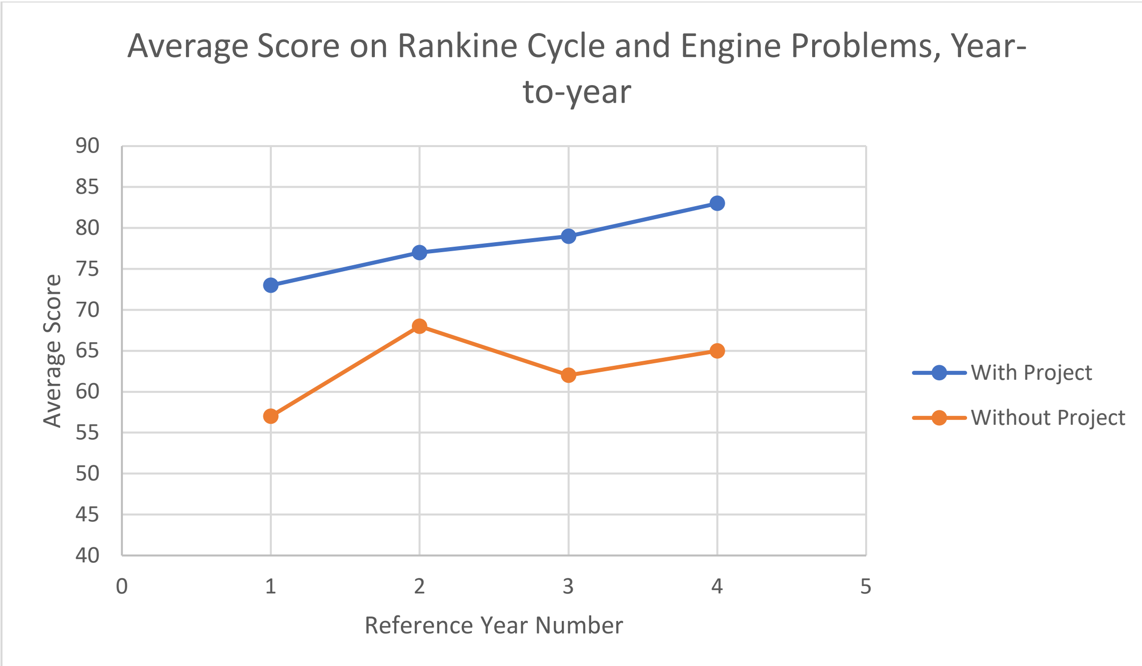

Figure 9: Year-to-year comparison graph of average scores on Rankine cycle and engine problems

Discussion and Conclusions:

After teaching Introduction to Engineering thermodynamics for four years, it was clear that students struggled on the final exam on two questions, one on the Rankine cycle, and the other on internal combustion engines. A project was introduced in which students had to design and present their own power plant or engine system. Since the introduction of the project, the average score on these two questions on the final has increased from 63% to 78%, a 15% overall increase.

I believe that this is a significant result. Although the numbers of students are not large, eighty-one students over ten years is an average of around ten students per class. At Marian University, that is a typical size class for upper-level math, physics, and engineering classes, so this would seem to be statistically relevant results. There is a chance the problems have started to leak, but this is a large increase in these specific problems, and no change in the rest of the final exam. If this was related to a leaked exam, I would expect all problems to increase. Since the final exams are not returned, the problems would only leak if a student was able to memorize the problem. All students have been told, for the entire eight years, that these topics would be covered on the final.

When I designed this project, I did so with the intent that a more hands-on, design based approach would be more popular with students, and a project they chose would keep their interest better than standard homework problems. As they work now with the project, the students are learning the method multiple times as they redo and re-calculate all the terms and take all the proper steps. As they apply these steps, they think through the problems more than if they are just trying to solve a textbook homework problem. Many engineering educators believe that implementing design into courses is useful as it better prepares students for future work. These results show agreement with that belief and show that students can learn topics better using the design aspect over homework problems. In addition, in having to present the project, they are required to understand the topic even more. I have thought for as long as I've taught physics and engineering that if students are able to present work and teach each other, it makes them have a better understanding of the topics.

Students were asked in final course evaluations to comment on the project for the past four years and asked for their opinions on the project and if they thought it helped them for the final. Although student evaluations are not always the most accurate, in this case, thirty-eight of the forty-four students have responded to this question, and all have had positive things to say about it. Some examples include "The project did help me in preparing for the final exam." and "I feel that the project helped advance my learning. I felt that the design project gave me a reason to think about these problems, and the real-world applications helped." One comment that stood out seemed negative at first, but turned positive in the end when the student said "I did not like having to present the project. I would have liked to just prepare a report. But, as much as I didn't like this, I think it did help me understand the topics better, as I had to go over it all many times to feel comfortable to present."

An increase of 15% is very good for these problems. In the future, I would continue to watch the scores for these two problems and see if they continue to increase. Over time, as the project is fine-tuned and used more, I would hope to see the average percent on the Rankine and engine problems become higher than the review questions students see on other exams during the semester. Future work on this project would include a more robust analysis of the grades within the demographics mentioned in the methods. It is an interesting thought to analyze the performance based on type of engineering major, male/female performance, ethnicity, foreign students, and other similar demographics.

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