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Pump Design Project for Large-Scale Thermodynamics Course

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Abstract

Education quality improves when students are able to apply their knowledge to real-world examples, particularly when students are able to move beyond just working through textbook problems and lecture notes. When working through conceptual design projects, this may be accomplished fairly easily in small class sections, for there are fewer practical limitations to evaluating all students' different design outcomes. However, this becomes problematic in larger class sections, for there are frequently limitations on the amount of instructor time and instructional support for grading open-ended design work.

To address these issues, a thermodynamics project was developed which put students into teams to design a pump system. These groups were in charge of an oil company. The company was charged with designing a pump system to pump oil from an endless underground reservoir to the surface of the earth. Students were given a series of different pumps and types of piping to use for their design. Students used a first-law based analysis to ideate these designs. Students also had options to operate their system during different time blocks and to add filtration to their oil. Financially, students would make back their money by selling oil. Students also addressed social considerations of their designs via a "social score."

Students submitted their projects in two parts. Groups first submitted a preliminary design, along with various calculations necessary to complete the design. Groups inputted their design parameters and answers into a Google form, where coding was done to automatically check and grade students' design parameters and corresponding calculations. Students were then permitted to optimize their design and resubmit their work, where they were competitively awarded points based on the financial and social metrics of their designs. Student adopted a variety of strategies for optimizing, with some groups choosing to optimize monetary cost, some groups optimizing social considerations, and some groups trying to address both.

Keywords

Thermodynamics, Projects, Large-Scale

Introduction

When students are able to utilize their knowledge for real-world scenarios, rather than plodding through more typical, textbook problems, the quality and robustness of their education increases.[1-3] Some students, particularly in universities with larger class sizes, may go through many courses without so much as thinking about the practical applications of the material they have learned, for material is often presented to them in such a way that it may be as quickly and efficiently digested as possible, particularly in larger course sections.

Many instructors of large course sections present material in accordance with this goal of efficiency, leaving little room for adjusting the course material, structure, or points of emphasis based on students' interests. When assessing students' knowledge, instructors of these sections frequently opt to assign problems out of a textbook, for many instructors simply do not have the time, or teaching support, to grade complex, open-ended, or design-based assignments. However, this latter group of assignments can foster students' curiosities about a subject and allow students to explore different facets of a discipline in greater detail, while also potentially cutting down on cheating and allowing students to think creatively.[4-5] Following similar work that was done before, an open-ended project was developed to be quickly graded for large-scale thermodynamics course sections.[6]

Project Description

Students assembled into groups of three or four and were tasked with designing a pump system to pump oil out of a vast, underground reservoir. The learning objectives were for students to apply the first law equation to pumps and to design a pump system that meets the energy requirements. Then, each group evaluated their designs based on the project criteria.

In order to generate a profit for investors, students needed to design a system strong enough to get oil to the surface of the earth. The top surface of the underground reservoir was always fixed at 200 feet below the surface of the earth; thus, students were to design a system strong enough to pump the oil upward by at least 200 feet. An initial upfront investment was needed in order to build the system, but with the oil that was pumped out of the ground, groups would be able to recoup their costs by selling the oil at a fixed price of $19/barrel. Although this figure is considerably lower than the current cost of a barrel of oil, this number was justified through other associated costs, such as storing and transporting the oil.

The system itself consisted of a series of pumps that would be used together to pump oil out of the ground. **Table 1** shows the pumps that students could select. Several pumps were devised with each given a different base cost (initial cost at construction), yearly maintenance cost (spread throughout the year), input power, and pump efficiency. Students were able to, and expected to, select multiple pumps for use in their systems, for this was the only way the system could provide enough power to pump oil to the earth's surface.

Table 1: Pumps

Pump Name	Pump Base Cost	Yearly Maintenance Cost	Power Requirement to Operate Pump (Input Power)	Pump Efficiency
Mini Pump	$3.95M	$3.01M	2.1 kW	14.3%
Small Pump	$4.20M	$2.82M	2.0 kW	11.5%
Normal Pump	$6.95M	$4.04M	3.3 kW	17.2%
Average Pump	$6.50M	$4.28M	3.4 kW	17.5%
Medium Pump	$7.45M	$4.51M	3.8 kW	18.9%
Large Pump	$9.95M	$5.03M	4.6 kW	19.7%
Grand Pump	$9.75M	$5.15M	4.5 kW	20.7%
Big Pump	$11.0M	$5.47M	4.9 kW	20.8%
Massive Pump	$12.2M	$5.69M	5.2 kW	21.3%
Huge Pump	$12.4M	$5.50M	5.1 kW	21.5%
Great Pump	$14.1M	$6.48M	5.9 kW	22.4%
Immense Pump	$14.9M	$6.26M	6.1 kW	23.6%
Mighty Pump	$16.1M	$4.74M	7.4 kW	20.0%
Stupendous Pump	$16.1M	$6.03M	7.2 kW	24.0%
Vast Pump	$17.9M	$8.16M	8.5 kW	22.5%
Gigantic Pump	$20.2M	$9.53M	10.2 kW	21.9%
King Pump	$24.2M	$12.8M	11.3 kW	21.6%

In addition to selecting the combination of pumps used to provide power to the system, students also had to select the piping used for the system. **Table 2** shows the piping choices that students had. Pipe selections varied in their costs per foot and yearly maintenance costs. This project was designed for a thermodynamics course, so in order to eliminate any complexities involved with solving for volumetric flow rates or needing prior fluid mechanics knowledge, different volumetric flow rates were prescribed to each pipe.

Table 2: Different Piping Materials

Piping Name	Cost per Foot	Yearly Maintenance Cost	Volumetric Flow Rate
Tiny Pipe	$100k	$10k	5 barrels per minute
Smallish Pipe	$142k	$11k	7.3 barrels per minute
Standard Pipe	$214k	$13k	9.4 barrels per minute
Median Pipe	$247k	$13k	10.9 barrels per minute
Colossal Pipe	$314k	$15k	13.7 barrels per minute
Absurd Pipe	$388k	$20k	16.9 barrels per minute
Tremendous Pipe	$405k	$21k	17.1 barrels per minute
Giant Pipe	$483k	$29k	19.8 barrels per minute
Enormous Pipe	$536k	$30k	21.3 barrels per minute
Cosmic Pipe	$553k	$29k	21.4 barrels per minute
Mammoth Pipe	$634k	$34k	25.0 barrels per minute
Gargantuan Pipe	$727k	$45k	27.9 barrels per minute
Hefty Pipe	$753k	$49k	28.1 barrels per minute
Jumbo Pipe	$876k	$64k	29.0 barrels per minute
Epic Pipe	$908k	$70k	30.0 barrels per minute

In addition to the financial costs associated with designing and maintaining the structure of the system, the electricity used to run the system also had to be considered. **Table 3** shows the cost of electricity during eight different, three-hour time blocks during a given 24-hour period. To reflect electricity price increases during peak hours, the cost of electricity varied by time of day.

Table 3: Cost of Electricity

Block of Hours	Electricity Cost
12:00 AM – 3:00 AM	$0.11/kWh
3:00 AM – 6:00 AM	$0.10/kWh
6:00 AM – 9:00 AM	$0.11/kWh
9:00 AM – 12:00 PM	$0.13/kWh
12:00 PM – 3:00 PM	$0.14/kWh
3:00 PM – 6:00 PM	$0.15/kWh
6:00 PM – 9:00 PM	$0.14/kWh
9:00 PM – 12:00 AM	$0.12/kWh

Based on the above design choices, groups were able to calculate the upfront cost of the system, the continual operating costs of the system, and the profit that could be generated by running this system. Using this information, the groups could then calculate how long it would take for them to break even. This was the primary financial deliverable of the project: the "payback period."

In addition to financial costs, social costs were also to be considered, for a company's image is also important. In order for students to consider social costs of designing and operating such a system, an additive "social score" was introduced to allow students to quantify the amount of social good or bad they were doing. There were two ways for students to influence their social score. The first way was for students to filter the oil that was being pumped via adding a filter (**Table 4**). Filtering the oil would make the oil cleaner, thus reducing the amount of pollution that the oil would put into the air. Including a filter would introduce a relatively positive social benefit. Filters incurred a one-time cost at construction.

Table 4: Filters

Filter	Cost	Social Score
Lite Filter	$5.00M	+3
Plain Filter	$10.0M	+6
Power Filter	$15.0M	+9

Additionally, groups had the option to either run or not run their system during any of the eight, three-hour time blocks prescribed in **Table 3**. If a group chose to run their system during all 24 hours of the day, they would be able to pump more oil, but the surrounding areas would be subject to continual noise, which would disturb the local population. This disturbance would be more significant during the normally quieter hours of the night, when local residents are more likely to be asleep. The social scores associated with operating the pump system during different times of day is shown in **Table 5**.

Table 5: Social Scores for Operating Times

Block of Hours	Social Score
12:00 AM – 3:00 AM	-20
3:00 AM – 6:00 AM	-30
6:00 AM – 9:00 AM	-20
9:00 AM – 12:00 PM	-10
12:00 PM – 3:00 PM	0
3:00 PM – 6:00 PM	0
6:00 PM – 9:00 PM	-10
9:00 PM – 12:00 AM	-20

Project Submission/Grading

Because of the vast number of possibilities that groups could come up with, it was relevant to develop a means by which to check students' designs, and corresponding calculations, accurately. This was done using Google forms and sheets. For the first part of the project, groups submitted their design specifications, as well as pertinent final calculations, into a Google form. This form allowed students to enter the number of every type of pump that was used in their system, all operating times for their pump system, the piping that was used, and various calculated quantities that would be required in order to verify that their system would work. These calculated quantities included the input power required for the system, the output power, the ratio of output power to the volumetric flow rate of the oil, the payback time of the design, and the overall social score of the design.

All groups' values were automatically uploaded into a Google sheet upon submission. This Google sheet contained coding and formulas written to easily handle the student inputs. Once all group submissions were in the Google sheet, with each submission being in its own respective row, then the formulas in each column were simply dragged down through all rows of submissions. The spreadsheet would then populate itself many columns' worth of data, intermediate calculations, and grades for each student, based on the rubric for the first part of the project (shown in **Table 6**). This first part of the project was worth 45% of the final project grade.

Table 6: Submission 1 Rubric

	5	3	0	Multi-plier	Total for Category
Coming up with Something	Design submitted by the due date		Design not submitted by the due date	1	
Workable Design	Design is strong enough to pump oil to the surface of the earth		Design cannot pump oil to the surface of the earth	5	
Calculation: Input Power		Calculation is correct	Calculation is incorrect	1	
Calculation: Output Power		Calculation is correct	Calculation is incorrect	1	
Calculation: Ratio of Output Power to Volumetric Flow Rate		Calculation is correct	Calculation is incorrect	1	
Calculation: Payback Time		Calculation is correct	Calculation is incorrect	1	
Calculation: Social Score		Calculation is correct	Calculation is incorrect	1	
					Total Points: ___ / 45

The second part of the project was similar in that groups were able to submit another design. Groups could simply submit the same design that they initially submitted, or they could submit an entirely different one. However, groups would be competing against each other for the design bid. A portion of the grade for this second part of the project would depend on how different groups' payback times and social scores compared to each other. No calculations were included in this second submission.

To accomplish this, coding was done that would evaluate the students' designs, in the same way that was done before. It was determined which designs were not sufficiently strong enough to pump oil to the surface of the earth, and these designs were removed from consideration. Any design that would not pump oil to the surface of the earth would not earn points for this part of the project, for they could not also be considered in any comparative analyses. All functional designs were then independently sorted by both payback time and social score. Groups were then given points based on how competitive their designs were relative to other groups. The rubric for this is shown in **Table 7**. This second part of the project was worth 50% of the final project grade.

Table 7: Submission 2 Rubric

	10	8	6	4	2	0	Multiplier	Total for Category
Workable Design	Design is strong enough to pump oil to the surface of the earth					Design cannot pump oil to the surface of the earth	2.5	
Payback Time (Competitive)	90th-100th% percentile	70-90%	50-70%	35-50%	15-35%	0-15%	1.5	
Social Score (Competitive)	90th-100th% percentile	70-90%	50-70%	35-50%	15-35%	0-15%	1	
								Total Points: ___ / 50

The remaining 5% of the project grade was based on peer evaluations within each group.

Student Feedback

After the project's conclusion, students were surveyed and asked to provide feedback about the project. In one of the survey questions, students were given 10 possible adjectives that could be used to describe the project, and students were asked to pick three to describe the project. The adjectives, along with the percentages of students who selected a particular adjective, are given in **Table 8**.

Table 8: Student Adjective List Responses

Adjective	Percentage of Students
Challenging	56.5%
Interesting	51.6%
Tedious	50%
Time-consuming	37.1%
Straightforward	37.1%
Useful	27.4%
Enjoyable	22.6%
Worthwhile	14.5%
Hard	11.3%
Unrewarding	9.7%

It was pleasing to see that the top two adjectives were "challenging" and "interesting," while the least selected adjective was "unrewarding." **Table 9** shows student responses to the statement: "The project improved my understanding of pumps and efficiencies."

Table 9: Student Agreement about Improving Understanding of Pump Efficiencies

Student Response	Percentage of Students
Definitely Agree	24.2%
Agree	46.8%
Neutral	14.5%
Disagree	4.8%
Definitely Disagree	9.7%

It was very pleasing that under 15% of students disagreed, in any capacity, that the project did not improve their understanding of pump efficiencies. Students were also asked to respond to the statement: "The project should have been done individually, rather than by a group." **Table 10** shows these results.

Table 10: Student Opinions on Whether the Project Should Be Done Individually

Student Response	Percentage of Students
Definitely Agree	12.9%
Agree	14.5%
Neutral	17.7%
Disagree	17.7%
Definitely Disagree	37.1%

Students seemed to be on board with this being a group assignment, rather than an individual assignment.

Discussion/Conclusion

The project administration and grading went well. There were no unforeseen issues with the coding, which contributed to a relatively clean handling of the inputted design parameters. There was, however, an issue with students unnecessarily including units in their responses to some of their calculations for the first submission of the project, although units were already specified in the submission prompts. This was fixed by manually going through all submissions and removing any included units; however, in future iterations of the project, it will be made clearer in the Google form prompts that only numerical values should be given as responses to the calculation-based questions, not units. Additionally, many groups asked questions about whether more than one filter could be applied to the system, though just one filter could be applied to the system.

There were many ways groups chose to optimize the second submission of their project. Some groups chose to very closely (or exactly) mimic the designs from their first submission, deciding that their design could not meaningfully improve at all. Some groups exclusively utilized only the smallest or largest pumps. Some groups, in an effort to try to guarantee a maximum possible social score, combined use of the strongest filter and operational times only from 12:00 PM – 6:00 PM, but these designs failed to generate any profit, leaving them earning no points for that competitive portion of the project. No group was able to simultaneously optimize both and social and financial aspects, which was encouraging to see from an administrative standpoint.

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