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Designing an engineering solution with the 4 P's: People, Prosperity, Planet, Politics

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Designing an engineering solution with the 4 P's: People, Prosperity, Planet, Politics

In this paper, I describe a simple method for introducing sustainability and assessing ABET criteria c, h, and j, in a 3rd year environmental engineering class. During this activity students pose design questions that incorporate 4 P's: People, Prosperity, Planet, and Politics. This allows students to examine their design questions within economic, environmental, social and political constraints (ABET criteria c). In addition this activity introduces contemporary issues (ABET criterion j). Finally this exercise can help students see value in the course material.

During the first week of an Introduction to Environmental Engineering class, students are asked to imagine themselves in one of three real-life engineering scenarios: 1. As an engineer in the Peace Corp who is asked to provide a treatment process for "turbid water that is making people sick" in the developing world. 2. As an engineer asked to design a process to remove contaminants from groundwater in Toms River, NJ. 3. As an engineer designing a statement before a board to defend a switch from coal to natural gas as a fuel source. First students are asked individually to write down all the questions they would need to ask before they design their process (and to whom they would ask them). Then they are asked to share their responses with their peers in a group setting and write down their responses.

The instructor then shows the students a framework using an additional scenario (odors emanating from a sewer). The instructor explains how the solution would involve not only a technical solution but also a consideration of the 4 Ps. The students are then asked to re-write their questions with the 4 Ps in mind. After the activity the students were asked to write down what they learned and what surprised them about this activity. These three scenarios are then revisited by the students at the end of the semester *after* they have learned the technical solutions.

In this presentation, I will discuss the students' responses before and after the framework was discussed and at the end of the semester. Without being prompted, most of the students did not ask questions about people (who would it affect), prosperity (how much would it cost), planet (what are the environmental impacts of the design) and politics (who would pay for it, who is responsible). After the framework was shown, all the student groups were able to apply the 4 Ps to their scenario. The ability of the students to recall the 4 Ps as part of their technical solutions at the end of the semester will also be discussed. In student surveys, most of the students commented that they learned that the technical solution is not sufficient to consider in an engineering solution. In addition, they mentioned the importance of asking good questions and working together as a team. They also mentioned being surprised about some of current issues and challenges facing Environmental Engineers. This presentation will conclude with a discussion about how students learn to design technical solutions and also recognize the importance of political, economic, environmental and social constraints.

Introduction

The goal of most third year Engineering courses is to teach students the technical knowledge they need to design engineering solutions. However, it has been recognized that students need to be able to design beyond just the technical solutions. In her book: The 21st Century Engineer, Patricia D. Galloway states:[1]

> *If engineers are relegated to the role of technician, they will no longer command the level of responsibility that will enable them to successfully compete in the global economy or assume the leadership roles that will enable them to elevate standards of living worldwide and provide enhanced protection of the environment.*

Similarly the National Academy of Engineers states:[2]

> *Thus, within the context of professional engineering practice, one must consider a system that includes … the economic, political, ethical, and social constraints as boundary conditions that define the possible range of solutions for engineering problems and demand the interaction of engineers with the public.*

Finally, the ABET accreditation addressed both the design constraints and the impacts of these engineering in their student outcomes c, h and j.[3]

> (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
>
> (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
>
> (j) a knowledge of contemporary issues.

Typically these non-technical constraints are introduced only during their 4th (or final) year in a capstone or design course. In this paper, we explore the impact of introducing these constraints and impacts *before* the students obtain the technical knowledge in a third year course. These constraints were framed within 4 Ps: People, Prosperity, Planet and Politics. The first three Ps are known as the pillars for sustainability. The author was first aware of the first three Ps by participating in the EPAs P3: People, Prosperity and the Planet Student Design Competition for Sustainability.[4] A quick web search reveals many companies that use the first three Ps for their definition of sustainability. In this study we added a fourth P: politics. Politics comes into play in most engineering decisions and is rarely discussed in the engineering curriculum.

The questions driving the research were: 1. Do the third year engineering students already consider the 4 Ps when approaching an engineering solution? If so, in what engineering challenges are they most likely to be considered? 2. Can students address the 4 Ps in engineering challenges after being given a framework? 3. What do students think that they learned from this assignment? What surprised them? 4. Do students retain the 4 Ps weeks after

learning the technical solutions? In addition this paper presents an activity that faculty can apply to their own courses to satisfy ABET Criteria c, h and j.

Materials and Methods

Eighty one students were enrolled in a 300 level Introduction to Environmental Engineering class at Penn State University. As shown in Table 1, the majority of these students (53%) were Civil Engineering students in their 3rd year. In addition, 11% of the students were Chemical Engineering students in their final year. Other majors included Environmental Systems Engineering, Meteorology, and Biological Engineering.

Table 1: Number of students in each major and semester enrolled in this course.

MAJOR	4th – 6th semester	7th – 10th semester
Civil Engineering	43	6
Chemical Engineering	5	9
Environmental Systems Engineering	7	3
Other	2	6
Total (81 students)	**57**	**24**

Questions #1: Do the third year engineering students already consider the 4 Ps when approaching an engineering solution? If so, in what engineering challenges are they most likely to be considered? Are they more likely to consider these while in a group?

On the second day of class, the students were given one of three different engineering challenges shown in Table 2. In each scenario the students were asked to individually develop a list of questions (and resources for answers to these questions) they would ask before designing the solution. They were not given any information about the 4 Ps before or during this assignment. This assignment was turned in and counted as an in-class exercise and counted as approximately 1% of their final grade.

The students were then put into pre-determined groups. These groups were designed to match students in similar majors and similar semesters. Once in the group the students were asked to share their responses with their peers in a group setting and write down their responses. The goal of this exercise was to see if students would come up with the 4 Ps while working as a team.

The students turned in both the individual and group assignments. The instructor looked at the questions the students posed and recorded whether the students mentioned any questions related to each of the four Ps. For example, student might ask a question about how the scenario is affecting the health of the individuals (people), or how much money is available for the solution (prosperity) or how the solution might impact the environment (planet). In addition the instructor looked for any mention of any political constraints. This could include questions like: Who is in charge of the water supply for this community? Who will do the work required for this solution?

Table 2: Engineering design scenarios presented to students during the first week of the semester. Each student is given one of the scenarios and asked to consider the constraints and sketch an idea of the process.

	Engineering scenario	Constraints?	Process
#1: Developing world water	You are a Civil Engineer in the Peace Corp. You are told that the water in the community where you will be staying is "turbid and dirty" and is "making people sick".	You are asked to design a water treatment solution for this community. Write a list of questions you would ask before designing your process. For each question, list a resource you would use to answer the question.	Sketch an idea of your process.
#2: TCE in Toms River	In Toms River, NJ there is a former dump site that is still leaking solvents (e.g. benzene, toluene, and trichloroethylene) into the aquifer. Your job as an environmental engineer is to design a process to remove the contaminants and protect the water supply.	What are some of the questions you would ask before designing the treatment process? For each question, list a resource you would use to answer the question.	Sketch an idea of the process.
#3: Natural Gas vs. Coal	Penn State is switching from coal to natural gas for heating. You are the engineer at Office of Physical Plant that is responsible for convincing the Board of Trustees that this is a good idea.	Make a list of questions you must get answers to before you can go to this meeting. For each question, list a resource you would use to answer the question.	Design your initial statement that you will make before the board.
#4: Odor emanating from sewer	You are called to a beach town during the busiest summer week. There is a strong odor emanating from the sewer near the bridge coming into town.	What are some of the questions you would ask before designing the treatment process? For each question, list a resource you would use to answer the question.	Sketch an idea of the process

2. Can they address the 4 Ps in these engineering challenges after being given a framework?

On the third day of class the instructor showed the students a framework for addressing a different engineering scenario using the 4 Ps. This challenge is shown as Challenge #4 in Table 2. In this challenge an engineer discovers an odor coming from a sewer at a beach town during the summer months. The instructor explained that the odor was caused by creation of sulfur gas due to anaerobic digestion of sludge in the sewer pipes. The technical solution is to scour the pipe to remove excess sludge and to possibly add an oxidizer to the pipe. After describing the challenge she introduced the idea of the 4 Ps. She then asked the class how the 4 Ps should be considered in this engineering solution and she listed these ideas on the board. Responses gathered included: How will vacationers be affected by the smell created by the treatment?

(People). Where will the effluent go when the pipe is flushed? Will it affect the wildlife? (Planet). Who will do the wok? Unions? (Politics), How much will it cost? (Prosperity)

With this framework in mind, the student were then again given the original assignment as a group and asked to frame the challenges (#1 - #3) with the 4 Ps in mind. This assignment was also turned in.

3. Do they retain the 4 Ps weeks later after learning the technical solutions?

During the semester the students learned the technical knowledge required to solve these engineering challenges. For example, they learned about how to remove microorganisms in water (water in developing world), how to quantify the environmental impacts of natural gas vs. coal and how to remediate contaminated groundwater. During the 13th week of the semester the students were given similar challenges to the first week. This time the challenges had more specifics and the students were asked to provide an actual process (Table 3). In addition, the students were handed the questions randomly. Each student completed the questions for one scenario. The students were specifically asked how the process will affect society and the environment. This was asked in order to satisfy our department's specific ABET criteria (c). The students handed in their responses at the end of the class period and this assignment counted as an in-class assignment. Again the instructor evaluated the responses using the 4 Ps as a rubric.

Table 3: Engineering design scenarios presented to students during the 13th week of the semester. Each student is given one of the scenarios and asked to consider the constraints and sketch an idea of the process.

	Engineering scenario	Constraints?	Process
#1: Developing world water	You are a Civil Engineer in the Peace Corp. You are told that the water in the community where you will be staying is "turbid and dirty" and is "making people sick". You analyze a water sample and find that the water contains dirt, bacteria and *Cryptosporidium*.	What must you consider before you start designing the process? Write down specifically how this process will affect society and the environment.	Sketch an idea of your process. List the function of each part of the process.
#2: TCE in Toms River	In Toms River, NJ there is a former dump site that is still leaking TCE (trichloroethylene) into the aquifer. Your job as an environmental engineer is to design a process to remove the contaminants and protect the water supply.	What are some of the constraints you need to consider before designing this process? This should include technical constraints as well as other constraints. Write down specifically how this process will affect society and the environment.	Sketch an idea of the process. State your assumptions (including the properties of the chemical).

#3: Natural Gas vs. Coal	Penn State is switching from coal to natural gas for heating. You are the engineer at Office of Physical Plant that is responsible for convincing the Board of Trustees that this is a good idea for Penn State.	What are some of the constraints you should consider before preparing your statement? This should include technical constraints and other constraints. Write down specifically how this process will affect society and the environment.	Design your initial statement that you will make before the board. You can state your assumptions here as well.

4. What do students think that they learned from this assignment? What surprised them?

After the assignment was turned in the students were given a survey. The purpose of this survey was to probe the impact on the exercise had on student's perception of what they had learned. This survey included 3 questions:

1. What is the most important thing you learned from this exercise? What did you learn that you may use in 10 years in your career?
2. What is the most surprising thing you learned? (or…what was your "Ah-ha" moment during this exercise?)
3. What would you suggest next time I use this exercise?

Results:

We were first interested in how many students would consider the 4 Ps when approaching various engineering challenges. Table 4 and Figures 1 – 3 show that typically less than half of the students mentioned people (who it would affect), prosperity (how much it would cost), planet (how it would affect the environment) or politics (how would the local politics be affected). The exception to this was in the natural gas vs. coal scenario. In this scenario, most of the students compared coal to natural gas based on cost (prosperity) and environmental (planet) impact.

Table 4: Percent of students who mentioned each of the 4 Ps in three ways during the semester. Individual pre represents the responses during the first week (before introducing the 4 Ps), Individual post represents the responses during the 13th week of the semester. 4Ps post represents the percent of students who specifically mentioned the 4 Ps during the 13th week.

Scenario	Individual pre				Individual post				4Ps post
	people	prosperity	planet	politics	people	prosperity	planet	politics	
Developing world (#1)	54%	29%	21%	4%	93%	82%	96%	54%	45%
TCE in groundwater (#2)	30%	17%	57%	9%	100%	84%	88%	52%	24%
Natural gas (#3)	25%	100%	96%	29%	93%	96%	100%	57%	4%

We then asked if getting students in a group would improve the likelihood that they would mention the 4 Ps. Figures 1 – 3 show little change based on "group-think". Although there are no error bars on this data (because there are so few groups), it is clear that students in groups

were only slightly more likely to come up with the 4Ps for each scenario. In addition there is also no difference between students in different major or semester standing (data not shown).

There was, however, a large change when the students were given a framework for applying the 4Ps. This data is shown as "Post-Group". In almost all the scenarios students were able to give examples of the 4 Ps after they were given the framework based on an additional scenario. The students were asked to revisit their challenge on the same day that the 4 Ps were introduced.

Finally we wanted to know if students would recall the 4Ps after they learned the technical content. Students were given the same set of challenges twelve weeks later. This data is shown as "End of Semester" in Figures 1 – 3 and as Individual post in Table 4. At this point they had learned the technical solution to these engineering problems. In addition to explaining the technical solution, they were asked specifically about the impacts of their solution. In this case more than 80% of the students mentioned questions pertaining to People, Prosperity and Planet. The exception to that was a discussion of politics in engineering design. Slightly more that 50% mentioned questions about politics for all challenges (See Table 4).

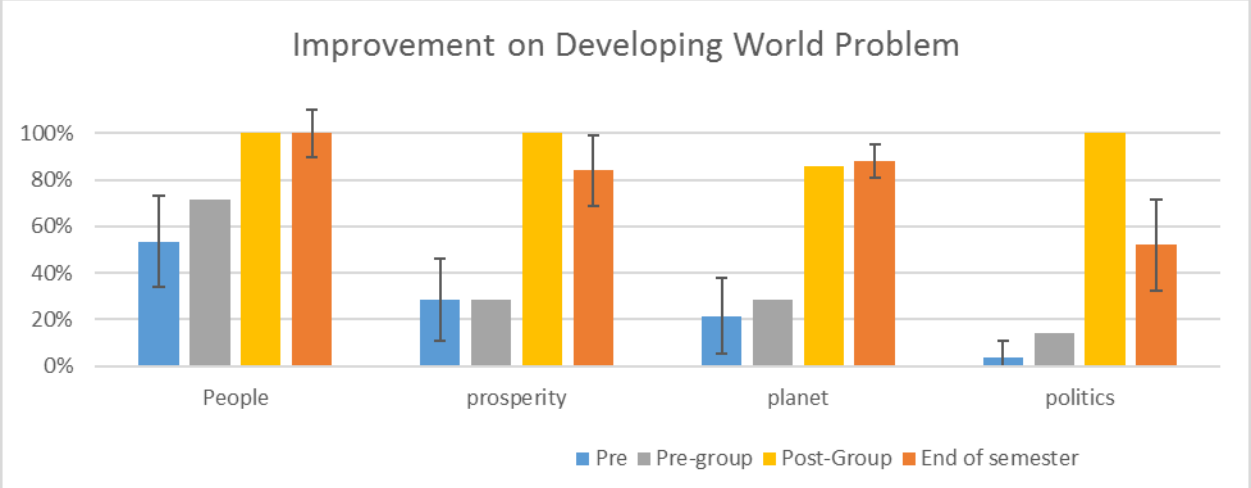

Figure 1: Students responses to the following challenge: You are a Civil Engineer in the Peace Corp. You are told that the water in the community where you will be staying is "turbid and dirty" and is "making people sick". The "Pre" and "Pre-group" represent individual students and groups of students, respectively who responded during the first week of class before being introduced to the 4 Ps. The "Post-Group" were the same groups after learning about the 4 Ps. The "End of semester" group represents individuals responding during the 13th week of the semester after learning the technical content. Most students did not think about the impact on the 4Ps before being introduced. After 13 weeks most students mentioned people, prosperity and planet but only half mentioned politics.

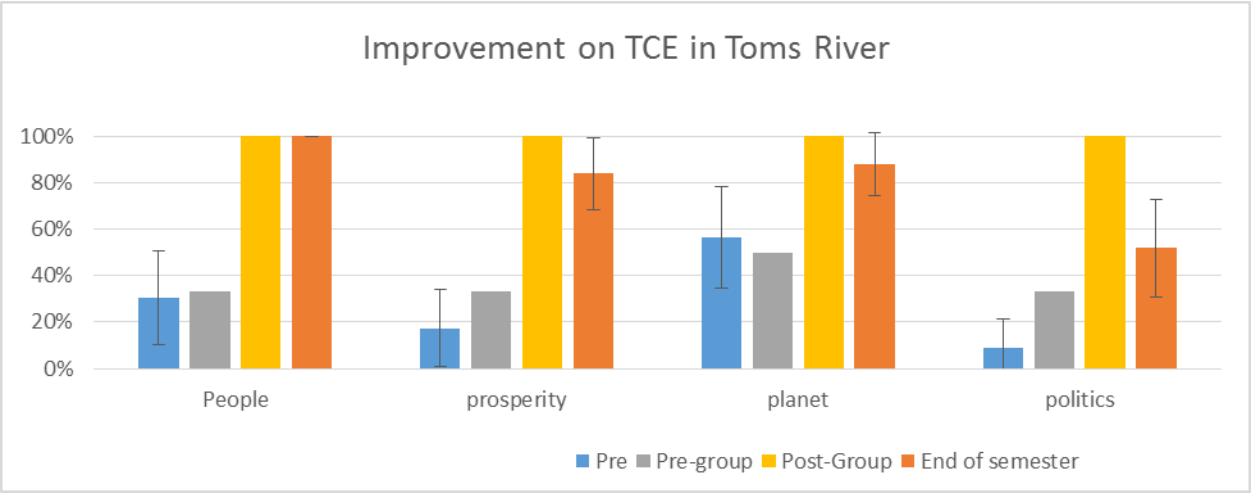

Figure 2: Students responses to the following challenge: In Toms River, NJ there is a former dump site that is still leaking solvents (e.g. benzene, toluene, and trichloroethylene) into the aquifer. Your job as an environmental engineer is to design a process to remove the contaminants and protect the water supply. The "Pre" and "Pre-group" represent individual students and groups of students, respectively who responded during the first week of class before being introduced to the 4 Ps. The "Post-Group" were the same groups after learning about the 4 Ps. The "End of semester" group represents individuals responding during the 13th week of the semester after learning the technical content. Most students did not think about the impact on the 4Ps before being introduced. After 13 weeks most students mentioned people, prosperity and planet but only half mentioned politics.

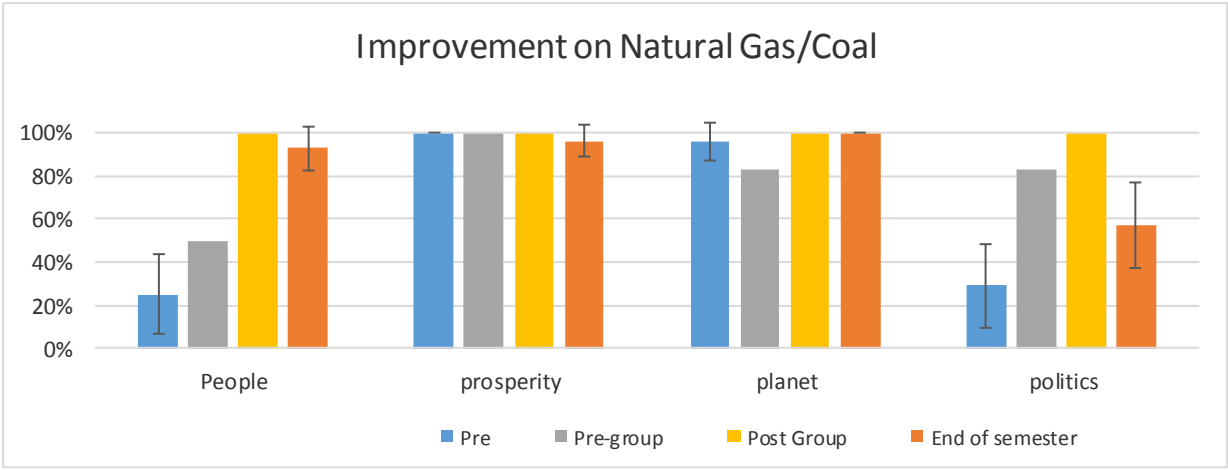

Figure 3: Students responses to the following challenge: Your University is switching from coal to natural gas. You are the engineer responsible for convincing the Board of Trustees that this is a good idea. The "Pre" and "Pre-group" represent individual students and groups of students, respectively who responded during the first week of class before being introduced to the 4 Ps. The "Post-Group" were the same groups after learning about the 4 Ps. The "End of semester" group represents individuals responding during the 13th week of the semester after learning the technical content. For this challenge most students thought about prosperity and the planet before learning about the 4 Ps but didn't think about people or politics. Student retained that

people, prosperity and planet after 13 weeks but only about half the students considered politics after 13 weeks.

After the exercise during the first week of the semester the students were asked what they think they will use 10 years from now and what surprised them the most. Table 5 summarizes the main themes that resulted from this question. Almost 60% of the students mentioned that they learned that engineering solutions required not just technical solutions. This was the main point of the exercise. "*Unlike answers to the questions in my other classes, true engineering answers don't have boxed answers."*

In addition, about 10% of the students mentioned the importance of asking questions. Being able to ask questions (and knowing to whom to ask them) is an important part of life-long learning. Also, about 10% of the students mentioned the importance of being part of team. Surprisingly, some students mentioned that they gained confidence from being part of a group for this exercise.

Approximately 10% of the students mentioned being surprised by some of the real life scenarios. This helps motivate student to learn by giving them context to the study[5]. In addition this could be expanded and use to assess ABET criterion j: a knowledge of contemporary issues. Finally 12% of the students mentioned being surprised how much politics could affect a solution.

Table 5: Students were asked to describe what they learned from this exercise and what surprised them the most. The answers were compiled into major themes. The numbers in the parenthesis represent the number of students who mentioned this theme.

Themes	**Example Quotes from students**
Solutions are not just technical (59%)	*After we learned about the 4Ps and had to apply it to the exercise it opened up a new realm of questions that I didn't think too much about before.* *Finding a solution is not as easy as fixing the one problem. The solution must satisfy all of the 4 Ps in order to be successful.* *The technical aspect is not the most challenging. The most difficult aspect is communicating with people and sharing ideas and solutions.* *Unlike answers to the questions in my other classes, true engineering answers don't have boxed answers.*
Asking questions is important (9%)	*The 4Ps act as a starting point for asking questions to solve an engineering problem*
Surprised by real life scenarios (11%)	*I thought it was interesting that Haiti cut down their trees.* *The most surprising thing I learned was the info in the problem statement. For such a serious and environmentally damaging problem, the story receives little to no press coverage or attention.*

	Surprising that all the scenarios actually happened.
Importance of teamwork (10%)	*Combining ideas with others to make new ones. We all looked at it from different angles.* *There may be a lot of times I do not know the answer. However, with a group a solution can be made.* *I gained confidence I talking to others and discussing my ideas openly* *"Ah-ha" moment was hearing ideas from group members that I would have never thought of.*
Surprised by impact of politics (12%)	*I learned was that water is such a big political issue.*

Conclusions

In conclusion this paper shows that students can learn how to design within economic, environmental, social and political constraints in their first semester of engineering courses. This can be documented and can serve as evidence of ABET criteria c and h. More importantly students are exposed to real life Environmental Engineering scenarios and learn that "true engineering answers don't have boxed answers".

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