Environmental Awareness in the Material and Energy Balances Course

Mr. Connor Robert Bilchak, Columbia University

Connor received his B.S. in chemical engineering from Manhattan College in 2014 and his M.S. from Columbia University in 2015. He is currently pursuing his Ph.D. at Columbia under the advisement of Sanat Kumar and Christopher Durning. His work involves the morphological control of polymer-grafted nanocomposites for increased flux and selectivity in vapor separations.

Dr. J. Patrick Abulencia, Manhattan College

J. Patrick Abulencia is an Associate Professor of Chemical Engineering at Manhattan College. He earned his PhD in Chemical and BIomolecular Engineering at Johns Hopkins University, and his BS in Chemical Engineering, at Manhattan College. Aside from engineering education, his interests include water filtration, alternative energy, and sustainability.

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Connor R. Bilchak,[1] J. Patrick Abulencia,[1]

[1] Department of Chemical Engineering, Manhattan College, Riverdale, NY - 10471, USA

***Abstract*— The materials and energy balances course is often the first in the chemical engineering curriculum, and provides many students their initial exposure to calculations in the field. This work aims at supplementing the concepts included in this introductory course through a simple design project that students can easily relate to. More specifically, they were asked to design a water reservoir using campus buildings as a guide for its volume, as well as consumption data based on their personal habits. Aside from providing meaningful context to a material balance problem, the purpose of this approach was twofold: 1) to promote awareness of the environmental impact of their daily habits, and 2) to gain a sense of scale. A comprehensive survey was administered to assess if the project improved student understanding within these two dimensions. Similar projects with different design frameworks (such as a power supply balance) could also be used to promote awareness in other future engineering challenges.**

I. Introduction

The traditional materials and energy balance course has been a staple in chemical engineering programs for decades, and remains one of the pivotal courses that aids in shaping student knowledge of the discipline. Due to its fundamental nature it is delivered early in the chemical engineering curriculum. Previous literature has reported the importance of the course, as well as its reputation as a weed-out course due to the difficulty of the course concepts[1],[2],[3],[4]. However, this course also often represents the students first significant exposure to the field of chemical engineering due to its placement in the curriculum, presenting an opportunity to expose the breadth of career paths available to them.

Felder and Rousseau's text is commonly used for material balances courses and advocates basic design assignments that aid in students understanding of the course material[5]. Design projects with an emphasis on specific large-scale environmental concerns would therefore be a potential means to introduce basic design concepts while also making participants aware of some of the far-reaching environmental impacts of society. To this end, students were assigned a project to construct a water reservoir capable of sustaining the local population. This project and the final report the students were asked to submit based on their calculations served multiple purposes. First and foremost, the design required of the students would necessitate the application of basic knowledge learned in a material balance course, reinforcing the concepts learned during regular class lectures. Additionally, the topic chosen extends beyond the traditional chemical processes used in the material and energy balances course, thus illuminating the broad applicability of the field. The inclusion of personal water usage allows students to better acquire a sense of scale, as well as create awareness of how drinking water is obtained.

This design project was also presented in the framework of an experiment report format. The Accreditation Board for Engineering and Technology (ABET) has repeatedly emphasized the importance of effective written communication skills, and how these areas need to be strengthened[citec6]. Students must be aware that their communication skills determine how well their message is communicated, a fundamental concern in the field[7]. By immersing the students in technical writing and providing constructive feedback in an introductory course such as this, students will be better prepared for future courses involving technical writing.

II. Project Overview

Chemical engineering students begin their studies with the materials and energy balance in the fall semester of their sophomore year. After four weeks of general class meeting of two 75 minute periods each week, students were given a project statement tasking them with designing a water reservoir capable of sustaining the residential population of the university (estimated at 3200 students). Fig. 1 lists the project statement and conditions given to the students. In an effort to simplify the designs, students were first asked to consider reservoirs with volumes equal to those of Horan Hall (an 11-floor campus residential complex with a small footprint) and the Leo Building (the 4-floor engineering building with a large footprint).

Your job is to determine:

a) Which site (i.e. Horan or Leo) to use for 30, 50, or 100 years.
b) If neither site is available, how high must the reservoir be in order to satisfy the specifications.

Specifications:

a) Assume that the reservoir is 70% (by volume) full at time = 0 years.
b) The water level never reaches below 20% (by volume) capacity.
c) Express volume in the reservoir using gallons

Fig. 1. Given project objectives

If neither of these sites were unable to accommodate the required volume of water, students were to calculate the reservoir volume required and design the reservoir height using the floor areas of either building site. In order to also facilitate the students awareness of environmental resource deficits and their own water consumption, students were asked to monitor and record their daily water use in gallons. This value was then extrapolated to serve the residential population of the college. During the first week, students regular consumption habits were tracked. The following week, students were asked to conserve water when possible to illustrate the design difference between an environmentally aware community and a standard model. Students were required to calculate the minimum reservoir volume that would fit these specifications and evaluate if such a design would be sustainable given current rainfall. All other design criteria (number of students to support, building volumes, rainfall data, and estimated consumption amounts) were left open to student interpretations and were evaluated at the conclusion of the project. This allowed for a broad range of creative solutions. The grading rubric for the project incorporated aspects from the design and calculations as well as the students argument and overall presentation. This ensured the students paid equal attention to the material balance portion of the report as well as the water consumption monitoring and presentation format. After completing the project, students were asked to complete an online survey aimed at evaluating the effectiveness of the project, including the application of material balance calculations and environmental awareness. Survey responses were collected within two weeks of the assignment completion date.

III. Results and Discussion

Student feedback from the online survey multiple-choice questions is shown in Fig. 2 (N=54). This represents two separate classes from the Fall of 2013 and 2014. The design statement, requirements, and criteria were not altered in any way between the two years. The survey aimed to elucidate the students opinions on the project from both a materials balance and design standpoint as well an environmental awareness one.

All of the students designs reached the conclusion that there are no reasonable reservoir designs that fit these criteria; most student solutions contained reservoirs with heights of 1,000 feet or greater, or surface areas that vastly exceeded those listed in the design criteria. Additionally, over 60% of the students felt their designs either underestimated or just met the actual reservoir volume that would actually be required. A number of student reports speculated that this may be due to their design being based solely on public supply (i.e., failing to incorporate sources such as transportation, electricity generation, etc.) which encompasses about 10% of typical annual use[8]. Over 80% of the students found that basing the reservoir foundation on areas that were familiar to them aided them in understanding the volume of reservoir volume that was required. This is important to note from both a design and environmental perspective, as it aides the students in estimation but also allows them to visualize the sheer volume of water that is needed to sustain both an individual as well as a sizable population.

The majority of students gathered their typical water consumption data and previous rainfall data from government sources such as the Environmental Protection Agency and National Oceanic and Atmospheric Association A list of common water uses and their average daily amounts per student are listed in Fig 3. The average daily water consumption without conservation per capita was 134.2 gallons, slightly higher than that of the surrounding area in 2009[9] of 125.8 gallons per day. Conserved water usage was 44% less by volume at 75.1 gallons. Over 70% of student water conservation efforts involved reducing the amount of time showering, which accounted for an average of 50.4% of their daily water use without conservation. Water use from showering also showed

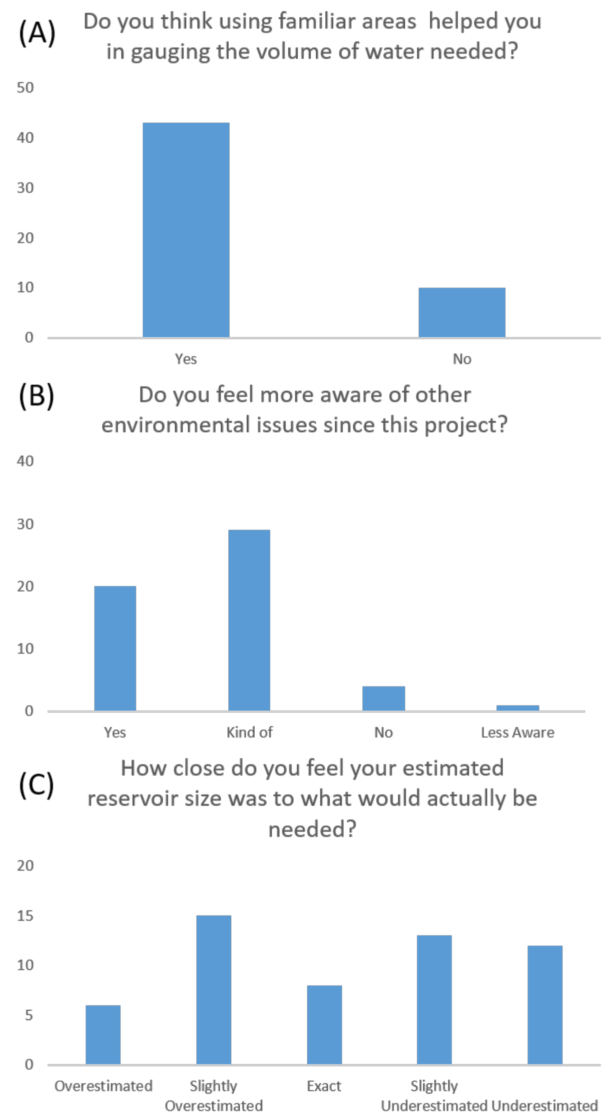

Fig. 2. Student responses to survey multiple questions regarding A) the efficiacy of using commonly known structures to gain a sense of scale, B) their awareness of environmental concerns after the projects conclusion, and C) how accurate they feel their reservoir design would compare to actual requirements

the largest percentage change between un-conserved and conserved practices, decreasing by over 58%. Students also made significant efforts to reduce the amount of water used for dish washing, which decreased by over 50%. Students were also asked if this project was helpful in elucidating the possible chemical engineering career choices, as well as how their views on the discipline have changed since before the project. Feedback concerning the application of materials balances to an environmental problem statement was also overall positive. The survey prompt and selected responses are shown in Fig. 4.

The majority of participants indicated their initial impressions of chemical engineering involved excessive work in experimental laboratories, and were not aware of the subjects environmental applications. A number of responses indicated that reservoir design was a task students did not associate with

Activity	Avg. Daily use without conservation	Avg. Daily use with conservation	Percent Change
Shower	73.75	30.27	-58.95%
Toilet	11.28	8.41	-25.44%
Laundry	22.86	15.55	-31.97%
Food/Drink	2.13	2.39	+12.33%
Dish Washing	25.8	12.28	-52.39%
Personal Care	18.55	9.88	-46.73%

Fig. 3. Common student activities that required use of water, and their average daily use both with and without water consumption. All units are in US Gallons.

How has this project changed your view of what chemical engineers do? Why do you feel it changed/did not change?
it opened up my mind as to the wide range of tasks a chemical engineer can complete
Yes. This project required a lot of thinking outside the box.
It kind of affirmed my view as chemical engineers have to factor in many different variables into solving a problem and there are multiple ways to solve a problem
It changed to encompass a larger focus on environmental applications. This is because of the project.
It didn't change much what I think about chemical engineering. But it did open my eyes about the environmental issues and how to approach them

Fig. 4. Selected responses to student opinions of chemical engineering

chemical engineering; as a result, students generally found that the scope of the design project broadened their understanding of chemical engineering applications. Additionally, numerous students commented on the level of creative problem solving and resource management required for a project with such an open-ended design, which are traditional design concepts vital to chemical engineering graduates. A number of students also reacted to the physical size of the reservoir that fit the design constraints, as well as the rainfall surface area that would be needed to sustain the designed reservoir. Additionally, approximately 50% of students indicated they have continued to conserve water as they were asked to do so for the design, or have similarly reduced their water use, as illustrated in Fig. 5. This represents approximately 60% of the students who responded yes or kind of more aware of environmental concerns in the multiple-choice segment of the survey (see Fig. 2) indicating that the project had sufficient impact for the majority of the students to adjust their water consumption habits.

While keeping many of the project specifications open-ended was thought to encourage creativity and allow for more unique designs, student response to this opportunity was mixed. The question prompt and selected responses are shown in Fig. 6. Over 20% of survey responses indicated this has more of a hindrance to their overall thought process.

Did your water habits/consumption change in the weeks after the project? Do you still practice these new habits?
I was more aware of my water consumption and would try and do little things like shut off the water when I'm brushing my teeth. I do still practice these new habits
Yes, it's hard to still practice the new habits.
My habits did change for a few weeks, but I no longer practice them as strictly as I did at that time
They definitely changed; the project helped me see how much water I was consuming and I became more conscious therefore after of how much I was using.
I've always managed to be conscientious of my decisions when it comes to my water usage. This project did reinforce why it is important to save water.

Fig. 5. Selected responses to students changes in water consumption after the completion of the project

Due to the many degrees of freedom allowed by the project, there were varying levels of accuracy in the students final reports; for example, a small percentage of students chose to estimate water consumption used for on-campus maintenance

What changes do you feel would most improve this project?
If the project had more detailed instructions telling and outlining exactly what we need to have.
Adding another source for input of water other than just rain fall.
More information about the format
I feel as though the clear stating of what dimensions can and cannot be would improve this project.
I think water usage should include food which I didn't do.
More guidelines and structure.

Fig. 6. Selected suggestions for project improvement

and food production, while the majority ignored this usage. These students naturally required larger-volume reservoirs that were more representative of real consumption. Other common suggestions included considering additional water sources, such as the network of natural reservoirs that support New York City, and incorporating more accurate and realistic reservoir areas. Approximately 10% of students also felt that the project could be improved by utilizing similar real-world applications of chemical engineering. This technique could be easily extended to other basic mass and energy balances that are relevant to course material, such as a power supply balance for energy consumption.

IV. Conclusions

In the process of designing a reservoir suited to sustain a local population, students became aware of the physical size of public utilities such as water supply, as well as gained a sense of scale of environmental resource consumption and availability. During the course of the assignment students consumed over 40% less water by volume on average, which approximately 50% of students continue to do well after the end of the project. Students generally indicated this change in water use arose from at least some increase in water use awareness. The format of the written component of the design also allowed students exposure to common principles in chemical process design, such as open-ended problem solving, which are commonly required and expected of chemical engineering graduates. This also served to elucidate potential career opportunities. However, a portion of students indicated the open nature of the design, while similar to what may be encountered in industrial applications, was too broad and did not provide adequate direction. This could be easily rectified by including additional design parameters or suggestions in the initial project statement. The simplistic layout of such a short design project makes its application easily tailored to other faculties that are commonly used by the general population, such as electrical power or food consumption. This not only provides students with a sense of scale for these general utilities but also permits them to gain awareness of a variety of industries that have significant environmental implications.

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