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Work-in-Progress: Fostering a Chemical Engineering Mind-set through Hands-on Activities

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Abstract

Work in Progress - In the Chemical & Biomolecular Engineering Department at Vanderbilt University, introduction to Chemical Engineering course have been offered previously. The style of both sections of course have been predominately lecture-based. When asked to describe the Chemical Engineering module, student focus groups did not remember what was taught in the module and labeled them as “not engaging”. In contrast, students were able to recall activities and projects from the other departmental modules. In this project, one of the two sections of this course was redesigned to include predominately hands-on activities that connect to chemical engineering concepts and a chemical engineering job. The activities were designed to engage students’ curiosity and connection to what chemical engineers do in the real world. The goal is that this new style of the Chemical Engineering module will better engage students and give insight to what chemical engineers do beyond graduation.

Background - Engineering courses are often perceived by students as heavily lecture-based, with a predominance on theory and mathematics and without translatable activities [1-2]. This can be problematic for students, who often do not fully understand the distinction between different disciplines or are wary about choosing an engineering major without connections to real-world applications [3-4]. Vanderbilt University is a partner in the KEEN, KERN Entrepreneurial Engineering network. The goal of the network is to increase student’s “entrepreneurial mindset”. This mindset can be summarized by the 3C’s: curiosity, connections and creating value [5]. Papers attempting to understand and improve the first-year engineer’s classroom experience demonstrate the ability of a course designed around the 3C’s improve student understanding of the topics and engage their interest in the major [6-9].

Description - As mentioned, this course was intended to better demonstrate the field of chemical engineering to first-year students while also stimulating their creativity, curiosity, and connections. Each of the activities lasted 50 minutes and tied to a chemical engineering concept that will be taught in the undergraduate curriculum. In this study, approximately 70 students took the intervention section of the course, and 74% (57) agreed to participate in the research project. One instructor taught all three modules [10] of the intervention course. The five activities utilized to achieve these goals are detailed below. Further information of our introduction to engineering modular course model can be found in Mahadevan-Jansen et al [10].

Activity 1 – Surface tension: The first activity introduced students to the phenomenon of surface tension and its applications in engineering disciplines. First, curiosity was engaged by discussing common water striders (insects in the family *Gerridae*) and their ability to traverse the surface of liquids despite being denser than the fluid. This behavior was simulated by students floating a paperclip in a cup of water. A small amount of vegetable oil was then added to the cup of water and the experiment repeated. As expected, the addition of oil prevented the paperclip from floating on the surface of the liquid. Finally, groups designed small boats from pieces of cardboard, wedging pieces of soap into slits in the boats as they saw fit. The boats were then placed into bins filled with water and allowed to traverse the bins. The task was to create a boat which travelled both the farthest and fastest using nothing but the force generated by differences in surface tension of the liquid caused by the dissolution of the soap. The activity was summarized by an open discussion of basic surface tension phenomena, explaining why oil inhibited paperclip flotation and how dissolution of soap could generate enough force to propel a boat. Finally, ties to chemical engineering were shown by highlighting career areas where surface tension effects are paramount (*inter alia*: crude oil recovery, paint design and manufacturing, food and beverage industries).

Figure 1. Examples of group-designed boats for exploring the phenomenon of surface tension. Some groups opted for a sleek and efficient design, while others were more creative, creating funnels for the soap to constantly replenish.

***Activity 2 – Freezing point depression*:** The second activity centered on freezing point depression using different concentrations of solutes. For this activity, a set of ice cubes was frozen for each group, with each set of ice cubes being comprised of a particular concentration of a solute (different salt, sugar, vinegar, etc. concentrations). The groups then added one ice cube of their particular solute to a cup of water and measured the temperature of the system at regular intervals until the ice completely melted. The experiment was performed in triplicate (to introduce students to the idea of repeatability), and all data were then aggregated in Excel. The subsequent discussion focused on introducing students to basic Excel functionality, such as graphing data, and comparing the solutes to determine which was most effective at lowering the freezing point (shown by the quickest melting ice cube).

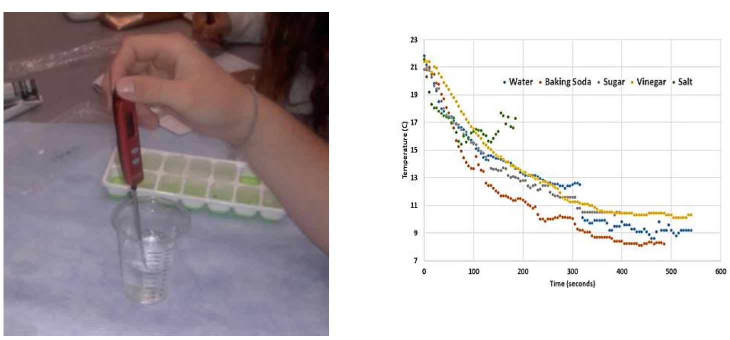


Figure 2. Example of how students collected the data. Each group used their own data set to plot graph, error bars and then comparison to control. Basic research protocols were learned.

Activity 3 – Water filtration: Groups were tasked with designing a filter system to remove impurities from an unclean water supply. “Dirty” water was created by addition of green food coloring and sodium hydroxide (final pH = 9). Groups were provided with standard coffee filters, common aquarium stones, sand, and activated carbon. Each group then designed their filter on paper, stating the desired mass of each component used and in what order. It should be noted that groups were not required to use all components, and some groups correctly identified the use of aquarium stones as superfluous, choosing to maximize filter efficiency and save space by disregarding this component. After the design step, the groups created their filter by adding their components to an inverted water bottle, which had the base cut off and the lid perforated by several pinholes. In this way, when the dirty water was poured into the base of the bottle, gravity filtration down the filter and through the pinholes in the lid occurred. Each filter was judged on its filtration time, color of collected filtrate (determined by sight), and pH of collected filtrate (determined by pH paper). A discussion was held to compare different groups' approaches and respective outcomes. This activity was then related to real-world engineering by highlighting engineering contexts which commonly use water filtration, such as waste management plants, consumer products, and low-resource devices for public health.

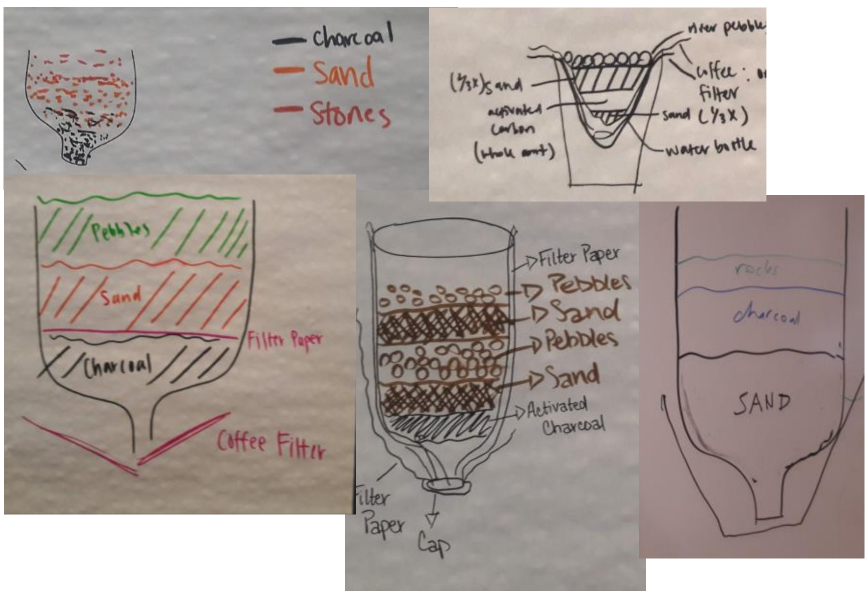


Figure 3a. Examples of group designs for a water filtration system using sand, pebbles, activated carbon, and coffee filters. Not only did the designs vary significantly between groups, but the creativity in planning and modeling their devices did as well.

Figure 3b. Filtrate of solutions from group's filters. The starting solution, shown at right, was flown through each group's filter and the filtrate judged on clarity, color, and pH.

Activity 4 – Mass balance: The fourth and fifth activities were interrelated, in that the fourth activity was designed as a "Research and Development" phase for the creation of a manufacturing plant discussed in the fifth activity. Groups were portrayed as R&D companies tasked to quantify the reaction of sodium bicarbonate and acetic acid to create carbon dioxide gas and waste products. Groups were allowed to react different amounts of each reactant, combining the reactants in an empty water bottle capped with a balloon. In this way, the carbon dioxide gas was captured in the balloon. The system was weighed before and after each reaction, in order to demonstrate the conservation of mass beyond chemical reactions or phase changes. Groups were also tasked with identifying the limiting reactant, and experimentally determining the minimum amount of each component needed in order to yield a specified volume of gas.

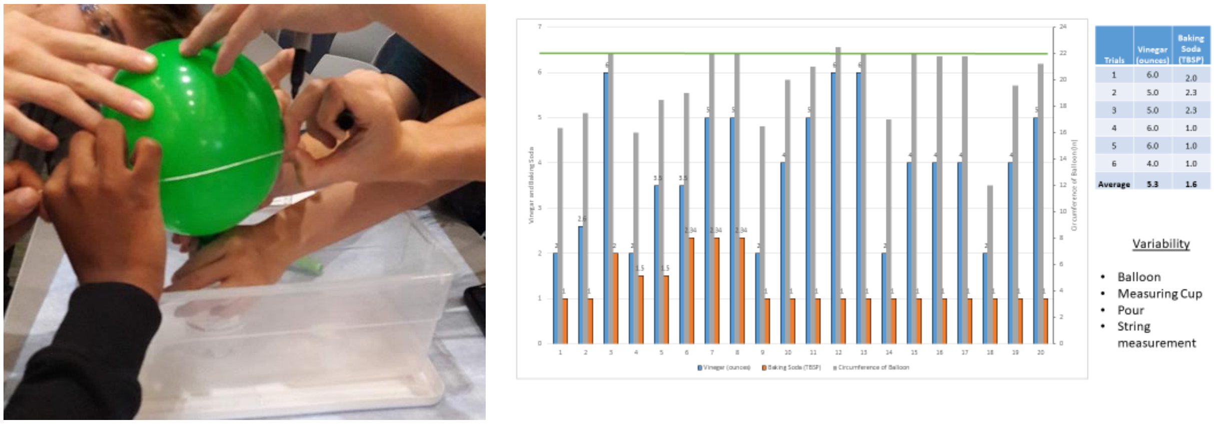
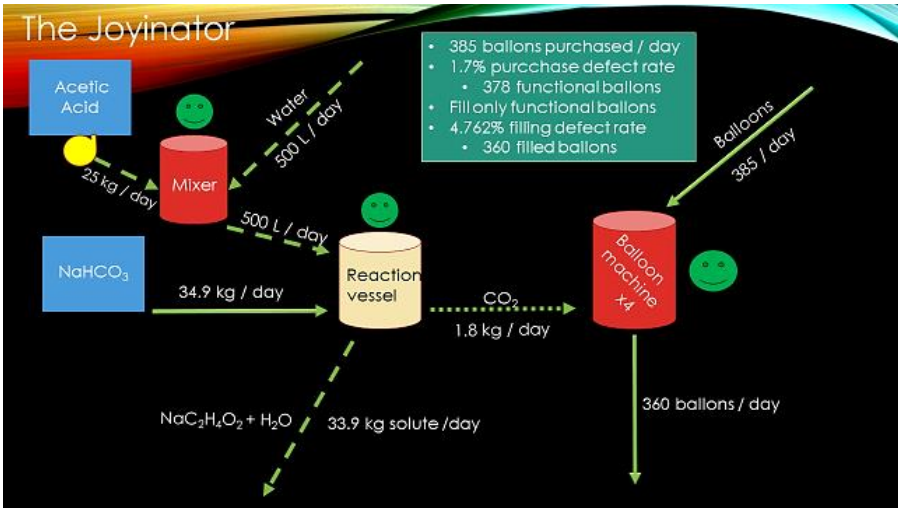
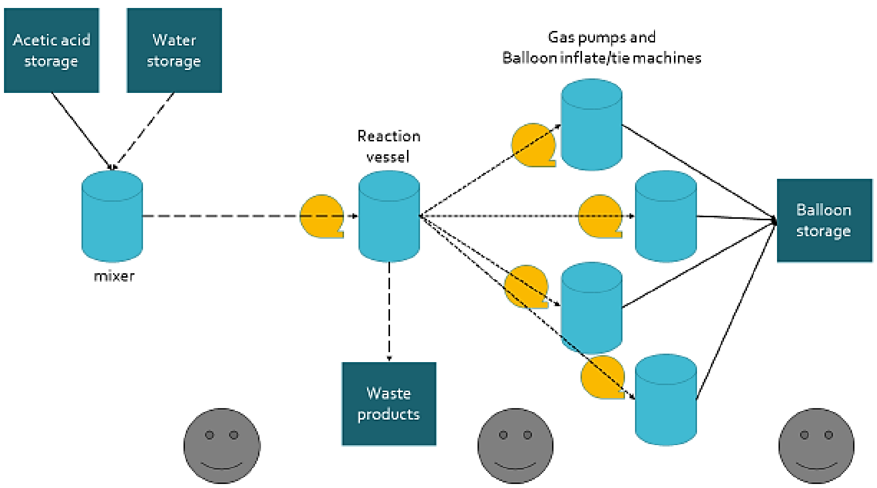
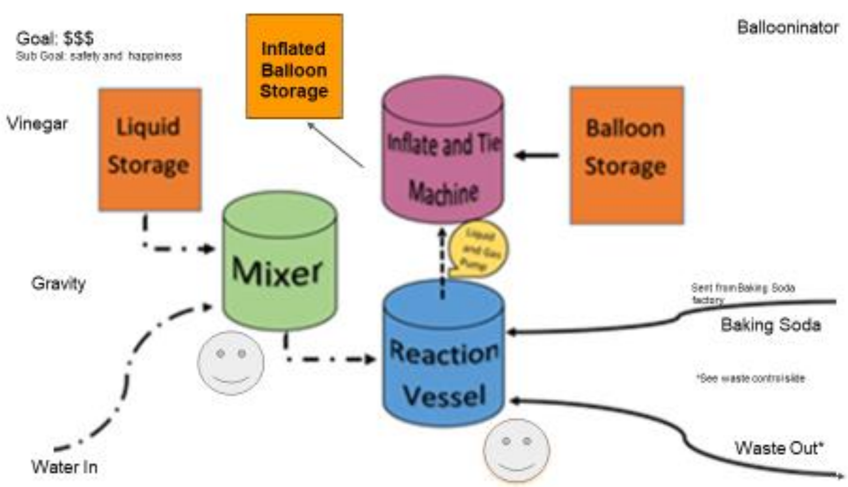


Figure 4. Students used the carbon dioxide generated from the reaction between baking soda and vinegar to inflate a balloon. Each group's data was aggregated in Excel in order to determine the limiting reactant well as the optimal combination to yield the largest balloon.

Activity 5 – Process development: Here, each group portrayed a consulting firm pitching their own creation of a manufacturing plant to produce inflated balloons. The groups were asked to scale-up their experimental results from Activity 4 in order to create a process plant capable of achieving a specified output of inflated balloons per day. The groups were given standard components (a mixing vessel, storage vessels, pumps, piping, a 'balloon-inflate-and-tie-machine', etc.), as well as costing information for each piece of equipment and profits generated per sold balloon. They were then asked to incorporate wants from two invested parties: a plant owner and a plant manager. The plant owner was described as primarily money-driven, wanting to minimize up-front costs even at the cost of safety, while the plant manager wanted to spare no expense in the creation of a more robust facility. From there, each group was allowed to design their own facility, culminating in a presentation to the interested parties (that is, the class instructors). The creativity and diversity of plants designed from these groups included such ideas as selling the waste products (which groups found is actually done in commercial facilities), using a gravity-feed system to minimize the use of pumps, and strategic placement of quality check stations to manage the impact of defective balloons and give thought to the potential safety hazards associated with the process. Groups were judged based on their creativity of process (such as including gravity systems or selling waste products), feasibility (based on their current engineering knowledge), economic analysis (judged by break-even time), and overall quality of presentation skills.


The Joyinator
Acetic Acid
Mixer
Water
500 L / day
25 kg / day
500 L / day
NaHCO$_3$
34.9 kg / day
Reaction vessel
CO_2
1.8 kg / day
$NaC_2H_3O_2 + H_2O$
33.9 kg solute /day
• 385 ballons purchased / day
• 1.7% purcchase defect rate
• 378 functional ballons
• Fill only functional ballons
• 4.762% filling defect rate
• 360 filled ballons
Balloons
385 / day
Balloon machine x4
360 ballons / day


Acetic acid storage
Water storage
mixer
Reaction vessel
Gas pumps and
Balloon inflate/tie machines
Balloon storage
Waste products


Goal: $$$
Sub Goal: safety and happiness
Inflated Balloon Storage
Ballooninator
Vinegar
Liquid Storage
Inflate and Tie Machine
Balloon Storage
Gravity
Mixer
Sent from Baking Soda factory
Baking Soda
Reaction Vessel
Water In
Waste Out*

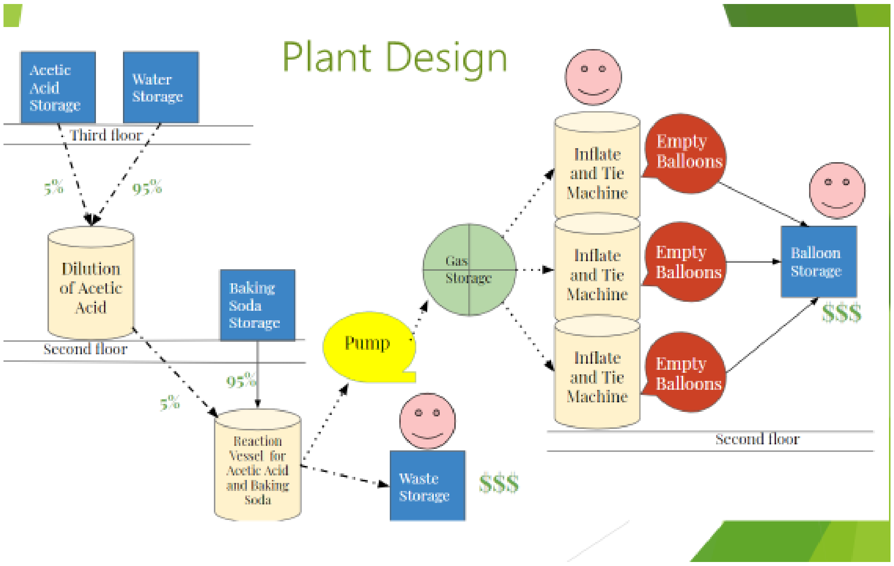
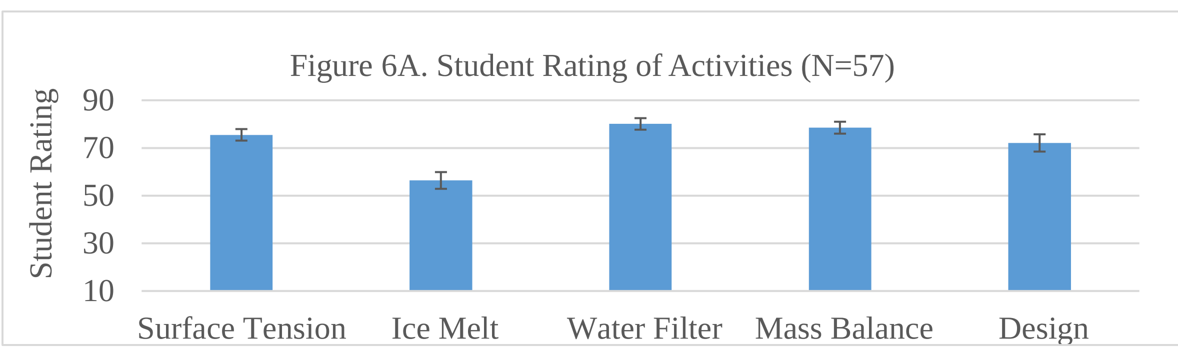


Figure 5. Various process flow diagrams from group presentations of the scale-up design project.

Preliminary Student Feedback - Students completed blind post-course surveys to provide feedback on the modules. This research project was approved by Vanderbilt's IRB # 191344. Students were asked at the end of the course to rate how well they liked the activity on a scale from 10 to 100. The responses were grouped based on student-provided demographic information and compared to determine which modules were preferred by which cohorts. Overall, the surface tension, water filtration, and mass balance activities were highly preferred, see Figure 6A. Conversely, the freezing point depression activity was the least liked module. In



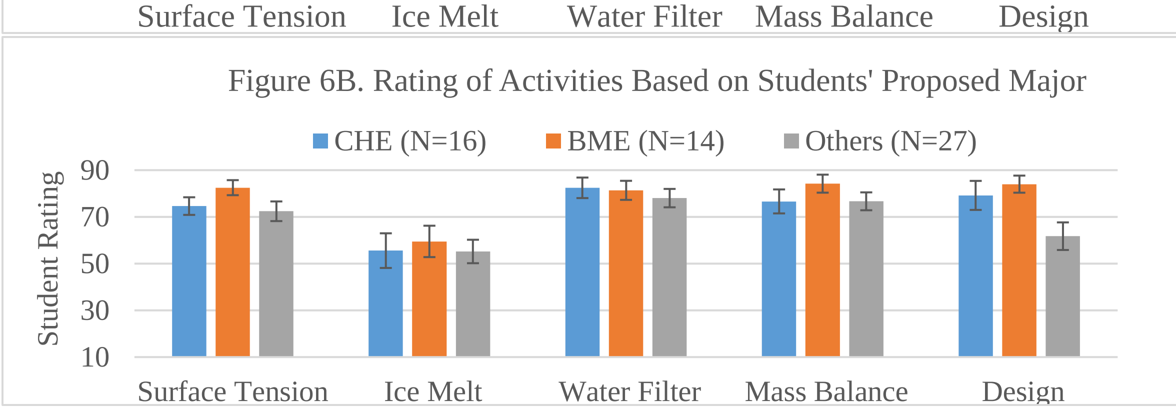


Figure 6B, the students whose intended major was not BME or CHE significantly disliked the design activity, p-value <0.01. This was to be expected since the activities were focused on chemical engineering concepts.

Future Work **–** Students' homework assignments will be designed to evaluate the connection to outside job market and to chemical engineering concepts. A rubric will be created from this coming Fall's student assignments and be used the following year to assess how students connect chemical engineering outside of the classroom. In addition, we hope that the increase in sample size will show more distinct differences amongst the groups.

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