Work in Progress: A Summer Outreach Program in Chemical Engineering Emphasizing Sustainable Technologies Related to Plastic Materials

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Abstract

This contribution will discuss some activities that were offered to high school students enrolled in the 2019 Summer Academy for Math and Science program at Carnegie Mellon University. During this program, students explored mainly the chemical engineering processes involved in soap manufacturing, polymer processing, their properties and applications. The goal was to raise student awareness in product design, manufacture and sustainability. Given the relevance and scope of the plastics crisis, we spent the majority of the class exploring how plastics contribute to waste and what strategies exist to alleviate this problem. Engineering aspects of the physical, mechanical and chemical properties of these materials were investigated. During the concluding ceremony of the SAMS program, a mini-symposium-style final project presentation gave students the opportunity to share their results and educate their peers about their insights on the role of sustainable engineering in their respective domain.

Introduction

The development of pipelines for students to introduce them to STEM careers before college and to increase their confidence in STEM-related skills is the key for the students' success [1-5]. In 2001, the Summer Academy for Math and Science (SAMS) program at Carnegie Mellon University was established to provide opportunities for rising high school seniors from underrepresented communities (i.e., students that belong to one or more of the following groups: first generation college students, low socioeconomic status, raised in a home where English is a 2nd language, underrepresented in science and engineering, as being African American, Hispanic/Latino or Native American, see Appendix 1 and 2) to explore STEM-related fields and earn college credit (Appendix 3). While the majority of summer bridge programs [3, 5] target students already accepted to a college for an intensive summer program, to be eligible for our school's program, students must be at least 16 years old by the program start date, and sophomores or junior in high school. Furthermore, students selected for the SAMS program must demonstrate commitment in community engagement, commitment to diversity as well as inclusion in education and extra-curricular activities.

The overarching goal of this program is to foster a sense of belonging for students in STEM, but also, to provide students a snapshot of college life at Carnegie Mellon University — its classrooms, teachers, dorms, and campus/community culture. Over the span of six weeks, students enrolled in the SAMS program will develop a deeper understanding in areas such as mathematics, biology, chemistry, physics and computer programming via traditional classroom instruction, hands-on projects and several activities (Appendix 3). Students select three to four courses within the program, participate in seminars, professional/academic development workshops, as well as engagement activities to foster collaboration and develop meaningful relationships with their peers from across the country. Students are being offered multiple homework-assigning courses including calculus, computer programming, a choice of biology, chemistry or physics, as well as hands-on project-based courses such as Chemical Engineering which is the subject of the present paper.

Research has shown that underrepresented minorities respond better to STEM education when activities are multi-media and hands-on [6-8]. To achieve the understanding of what an engineering career entails, the Chemical Engineering hands-on project-based course applies an experiential learning approach to lectures and laboratory experiments to expose the enrolled students to data analysis, material property estimation, basic process flowsheets, problem solving strategies, and team dynamics. The processes involved in soap manufacturing [9], polymer processing (in particular "traditional and bioplastics"), their properties, applications and mostly, their impact have been investigated. The emphasis has been mostly focused on "plastics" and sustainability.

Approach/Work plan

This project-based course in Chemical Engineering provides opportunities to make STEM "real and relevant" – by illustrating the role of engineering practice in advancing solutions to problems of global reach. Every day approximately 8 million pieces of plastic pollution find their way into our oceans. In 2016, a global population of 7 billion people produced over 320 million tons of plastic [10]. Plastics are a cheap, convenient, and effective way to supply an ever-increasing demand for products and services. Traditional plastics contain harmful chemicals (such as bisphenol and phthalates that disrupt hormones) derived from crude oil, can end up in ecosystems and disrupt natural habitats.

The goal of this hands-on course is for students to gain practical insights into 'what Chemical Engineers do', how the manufacture and processing of different substances are accomplished, and what some of the environmental ramifications are. Students learned that a chemical engineer aims to improve and make more efficient the chemical manufacturing process of several everyday materials while meeting the strictest environmental standards. Throughout a series of activities, students learned how to sketch basic process flowsheets, made bath bombs (soap fizzies) [9, 11], measured their lung capacity after blowing bubbles from soap solutions, calculated their carbon footprint and were asked to reflect on a cow's breath as well as an industrial plant and the environmental effects of energy use for bioplastic manufacturing.

Given the relevance and scope of the plastics crisis, we spent the majority of the class exploring how plastics contribute to waste and what strategies exist to alleviate this problem. Students learned how bioplastics are made from renewable biomass such as vegetable fats, oils, corn-starch, milk and other bio resources. They explored biodegradability and what components in cornstarch and milk could make effective bioplastics. Engineering aspects of the physical, mechanical and chemical properties of bioplastics were investigated.

A brief summary of each module for the lectures and hands-on activities of the chemical engineering course, with the most important steps is described below:

Module 0: Introduction to Chemical Engineering and Lab Safety

The focus of this module is to introduce students to engineering concepts and show that engineers design, conduct experiments then analyze and interpret the data. Students learned that engineers 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. The field of Chemical Engineering includes specific applications in cosmetics, medicine, clothing, food additives and toys. The process of making soap was discussed in detail and students learned how to design a flowsheet that accurately describes the steps involved in making a product. Before starting the hands-on activities, students were trained in basic laboratory safety.

Module 1: Solutions, Suspensions, and Colloids

To develop an awareness of the part played by an engineer or scientist in the formulation and processing of the daily use of the products such as oils, soaps, cosmetics, food suspensions, etc., students learned the difference between solutions, suspensions and colloids and how the different ingredients would impact the final product. Through examples such as, a sample of sugar dissolved in water and taken from the top of a glass, would taste the same as another sample taken from the bottom of the glass, students learned that in a solution, the solute breaks down into individual molecules within the solvent resulting in a homogeneous combination. The definition of a suspension has been illustrated using a tablespoon of soil mixed with water in a test tube, vigorously stirred then once we stopped stirring, students watched the soil particles swirling around in water before finally settling in the bottom of the tube. Finally, students learned that emulsions are a type of colloids made of tiny particles suspended in another immiscible material and milk is an emulsion of liquid butterfat globules dispersed in a water-based solution. Furthermore, to understand its importance in cosmetic and household products, a lecture with some online videos and hands-on activities on pH were presented and, pH measurements on several solutions, suspensions and emulsions were made. This module helped students to reflect on the ingredients and processing of the bioplastics and their conclusion was that ingredients must contain pH adjusters to prevent bacterial growth.

Module 2: Soap Bubbles and Bath Bombs

During the course of this module, students learned first the concept of soap bubbles, chemistry of soap molecules, what causes the soap bubble to be spherical and iridescent. Several online videos were used to instruct students about the science of soap and soap films. Students enjoyed making soap bubbles using 3D frames and blowing bubbles. They measured their lung capacity and calculated their carbon footprint and were asked to reflect on a cow's breath as well as an industrial plant and the environmental effects of energy use for bioplastic manufacturing. This activity was followed by making bath "fizzies" after sketching the basic process flowsheet and selecting the proper ingredients. This activity helped students to understand that these bath bombs "fizz" when placed in water because of a chemical reaction between two of the ingredients: sodium bicarbonate and citric acid. These two ingredients as they are in contact with water, react to form carbon dioxide gas, the "fizz". Furthermore, this module helped students to understand what Chemical Engineers do to make a product and what do they need to know to achieve the whole process.

Module 3: Polymers

Polymers have existed in natural form since life began and naturally occurring polymers have been used as materials for clothing, shelters and other tools. The origins of today's plastics industry were based on – in a large part - modification of natural polymers. Polymers have good mechanical properties and are easily formable. These features have made polymers the most relevant engineering materials by volume. Several lectures and online videos were used to teach students about polymers, their processing, and why they are found in basic everyday items.

In this module, we started the hands-on activities by first investigating the use of polymers in super absorbing materials, such as sodium polyacrylate where, students learned about osmosis and the different applications (such as, diapers) of such polymers. To explore the effect of the temperature on polymers and to learn about the manufacturing processes such as extrusion, melting, flow direction, etc., students designed and colored different shapes of Shrinky Dinks –biaxial stretched polystyrene sheets. Upon heating the sheets in an oven, students observed how the material returned to its original (pre-stretched) shape. This was used to convey the role of polymer chain (random walk) conformation. Another example of a widely used polymer material that was introduced to students is Acrylonitrile Butadiene Styrene (ABS), that is found in basic everyday items such as kitchen appliances, Lego toys, 3D printing, etc. ABS has gained popularity because of its combination of favorable properties such as chemical and thermal stability, toughness and strength (due to the rubbery dispersed particles of butadiene, ABS absorbs more mechanical energy and plastically deforms without breaking). Students explored the application of ABS as feed in 3D-pens that allow illustration of 3D print processes. Using these pens, students 'print fabricated' the chemical structure (in Lewis valence bond notation) of common polymers. They experienced ABS flows under heating, its extrusion through a slot die and analyzed challenges and limitations of the process. Hydrogels were also explored to highlight pharmaceutical/biological applications of polymeric materials.

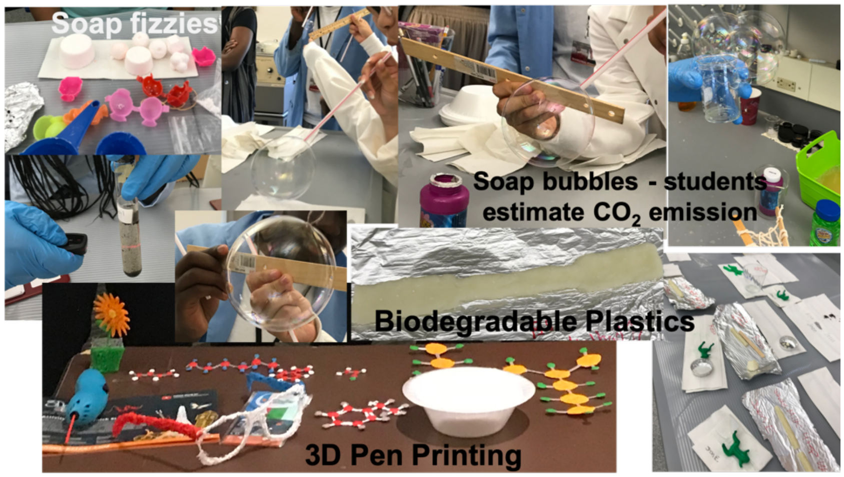
Finally, after highlighting the various applications of polymers we discussed how plastics contribute to waste. We introduced students to different strategies to alleviate this problem. One such strategy was the replacement of synthetic materials with bio-sourced materials and, students made two different bioplastics using milk and corn starch as main ingredients and, compared the final products against the "traditional plastics". First, flowsheets were sketched, followed by "manufacturing" of the products and finally, testing the mechanical properties of the traditional plastics and their bioplastic counterparts. Finally, students were asked to reflect on the potential degradation processes that bioplastics can incur, for example, due to pesticides and pollutants associated with agricultural processing. Students observed the formation of fungi on plastics from milk and corn starch, a common degradative process the prevention of which requires the use of chemicals and postprocessing. Mechanical properties were determined by tensile test measurements and students learned the concept of stress and strain. The results revealed that bioplastics lacked some of the performance characteristics of their synthetic counterparts.

Module 4: Stimuli-responsive Polymers and their applications: Microfluidics

This module explained laminar flow, what a microfluidic device is and their many uses in the field. Shrinky Dinks were used to replace etched silicon wafers, making the lab more cost-effective and scalable [12]. Several designs have been printed onto the smooth side of the Shrinky Dinks and then heated in an oven to explore the response of polymers under heating. Students prepared and poured PDMS (another type of polymers) over the Shrinky Dink mold to generate their microfluidic devices. When ready, dye solutions were fed into the devices to show laminar flow, mixing, and gradient generation. This activity has twofold objectives: (*i*) influence of stimulus temperature on the response of polymeric materials and their diverse applications for controlled drug delivery, (*ii*) training in advanced process technologies that promise higher efficiency as compared to established methods.

Module 5: Final Symposium

The last week of the SAMS program, students had to prepare and deliver a presentation to an audience consisting of all enrolled students, some key organizing personnel and family members. They selected their partners and parts of the main project i.e., plastics and sustainability. Teamwork skills were developed as students decided how best to convey their experience to the audience of family, friends and University affiliates. The final symposium allowed students 10 minutes per presentation and a short show-n-tell demonstration (see illustration below) of what they had made during the Chemical Engineering hands-on summer class.



Some highlights of the Chemical Engineering hands-on Activities.

Evaluations – Daily Reflection/Students' Reactions/Personal Interviews

By the end of the first week of the SAMS program, students were asked: "What is their thinking when they arrived at the University?" Some of the students said: "I do not know how to describe how I am feeling", others said: "I am excited … but apprehensive about the experience because I have never been away from home". A majority of students mentioned their worries about responsibilities once back at home and not knowing how to balance all these responsibilities.

During the program, students were often coming early to our chemical engineering course and we took the opportunity to ask them about their general impression of the school, the classes that they were taking and the workload they experienced. During each class, while learning was taking place, or at the end of the lecture/lab session, students were prompted to reflect on each lecture or activity they were exposed to. Their feedback helped us to revise our scheduling and plan for the next lecture/hands-on activity and make changes as necessary. To get a better understanding on the students' expectations and their learning goals, we asked the students about their favorite subject areas and academic as well as career goals.

Program's Assessment (provided by the program's Administration)

All faculty submit an assessment (self-efficacy, self-reflection, creativity and innovation, collaboration/teamwork, problem solving/critical thinking, etc.) on every student on their roster. Students complete a faculty evaluation and write a very short paragraph that includes general feedback as they continue to pursue STEM, feedback regarding specific skills needed in their development as students i.e., time management, etc. Furthermore, faculty/staff nominate students who (*i*) demonstrate initiative, perseverance and commitment to academic excellence throughout the entire program, (*ii*) exemplify the values and ideas of the [program], (*iii*) demonstrate and advocate for a greater understanding of our social responsibility to improve the lives of others via the various academic disciplines (SAMS program, faculty orientation reference).

The 2019 student satisfaction survey conducted by the program director showed that 41% of students described themselves as more academically ready to attend college, 37% of students felt more self-confident, 41% students described themselves as being more able to interact with their peers and 45% of students felt stronger in their ability to apply scientific theory to practical applications. Finally, the analysis of College choice before and after the program showed that 55%

of students were interested in choosing our University after completing the program (private communication, program administration).

Conclusions

Overall, faculty engaged in the SAMS program created a learning environment that allowed for students' strengths to be recognized and, fostered a dynamic academic and learning community that supported students' curiosity for learning. The Chemical Engineering course was well received - students were very engaged in the hands - on projects and one of the students received during the final ceremony of the program, one of the awards described above. Several comments were made by our students such as, students enjoyed the team accomplishment and took pride in discovering they were able to work in teams and solve difficult and "real world" problem such as sustainability. This course gave to students the opportunities to engage in collaborative work allowing them to exchange ideas, learn how to solve problems and work together towards the common goal that is sustainability. The verbal feedback from the students tended to be overwhelmingly positive at the end of the program.

Finally, to gather qualitative data on how the SAMS program affected the students' learning, the mini-symposium-style final project presentation during the concluding ceremony of the program gave the students enrolled in the chemical engineering course, the opportunity to share their experience and results (oral presentation and some demos) to the audience of family and friends and University affiliates, on bioplastics and educate their peers about their insights on the role of sustainable engineering. Their conclusion was that "*as chemical engineers, it is up to us to innovate new technologies, design the new materials that will allow us to sustainably prosper in the future*" and they will use their learning going forward.

Using examples to demonstrate and apply STEM's role helped students' understanding of how STEM can address larger societal issues. Finally, our Chemical Engineering project-based course may aid in increasing undergraduate enrollment in Chemical Engineering as well as answer in part, the question "What Do Chemical Engineers Do?".

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Appendix 1: SAMS Program Participants (provided by the program's Administration)

- 2019: 137 Total Participants
  - Piloted CS Juniors Cohort (20 students)
  - CS Seniors Cohort (26)
  - Science & Engineering Seniors (91)
- 2018: 114 Total Participants
- 2017:138 Total Participants

Appendix 2: Demographics Overall (provided by the program's Administration)

Gender

- 52% women-identifying (42% of CS Cohort)
- 48% men-identifying (58% of CS Cohort)

Race

- 55% Black and African American (7% of CS Cohort)
- 32% Hispanic and Latinx (38% of CS Cohort)
- 7% Native American (4% of CS Cohort)
- 10% Multiracial
- 3% White

<u>Appendix 3</u>: 2019 Curriculum (provided by the program's Administration)

	Academic Core	Academic Breadth	Project Based Learning
Computer Science Junior (20)	Discreet Math Pre-Programming	N/A	Select based on preference
Computer Science Senior (26)	Math (for credit, by placement) Programming	Select from: SAT Prep/Math Subject II/College Admission Essay Writing/Entrepreneurship	Select based on preference
Science and Engineering (91)	Math (for credit, by placement) Physics/Chemistry/Biology	Select from: SAT Prep/Math Subject II/ College Admission Essay Writing/Entrepreneurship/ Basic Programming	Select based on preference