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# ”We’ve got the solutions!” A chemical engineering high school summer camp

**Dr. Leah Granger, North Carolina State University**

Leah Granger is a postdoctoral researcher for Engineering Education and a course instructor for the Chemical and Biomolecular Engineering Department at North Carolina State University.

**Dr. Lisa G. Bullard P.E., North Carolina State University**

Dr. Lisa Bullard is an Alumni Distinguished Undergraduate Professor and Director of Undergraduate Studies in the Department of Chemical and Biomolecular Engineering at North Carolina State University.

# *WE'VE GOT THE SOLUTIONS!*
# A CHEMICAL ENGINEERING HIGH SCHOOL SUMMER CAMP

**Keywords**: Outreach, high school, demonstrations, recruitment

## Introduction

In an effort to encourage students to consider engineering as a career path, universities have instituted a wide range of programs, including research experiences, internship opportunities, transition programs from high school to college, and summer programs. The type of program varies based on the target audience, i.e. elementary, middle, or high school students; underrepresented students; rural students; or first-generation students, to name a few. The program type also depends on the resources available, both financial and human, with some programs involving a single visit to a classroom, while others may include a virtual or on-campus experience of a day, a week, or multiple weeks. In particular, engineering and technology summer camps have been shown to improve the confidence, value, and future intentions of both male and female participants [1]. Informal learning environments like those of camps can increase student engagement in STEM topics [2], and hands-on design experiences have been shown to build confidence and interest in engineering [3]. While there are a greater number of science-related summer camps, the number of chemical engineering-specific camps is less prevalent. There are examples of chemical engineering departments that have offered both in-person and virtual summer high school camps in chemical engineering, including Case Western [4], Purdue [5], Lamar University [6], the University of Buffalo [7], the University of Illinois [8], and Stanford University [9]. In this paper we will focus on a one-week on-campus summer camp offered at North Carolina State University for rising juniors and seniors in high school.

## Background and History

As part of the North Carolina State University College of Engineering's (COE's) outreach program [10], the Chemical and Biomolecular Engineering Department has offered a summer chemical engineering camp for high school students for more than 25 years. One of the authors has directed the camp since 2001 and has witnessed how the structure and content of the camp have evolved over time. Prior to 2018, camp activities centered around a single project – a fuel cell car – that students would build, test, and modify throughout the week. The camp has since changed to incorporate several smaller projects that better emphasize the variety of fields within chemical engineering. The current version of camp organizes activities into theme-focused days – biotechnology, nanoscience, sustainability, and process/separations – and includes demonstrations, tours, and activities that address each area. In 2024, a student workbook was created to provide resources and to guide students to make connections among activities.

## Structure

North Carolina State University has an extensive outreach program housed in the College of Engineering [10]. This program conducts both on-campus and remotely located summer day camps for elementary students, middle school students, and rising 9th and 10th graders. In addition, it offers residential on-campus summer programs for rising 11th and 12th grade high school students that are hosted by each engineering department. Students arrive on Sunday afternoon and depart after lunch on Friday. Monday through Thursday from 9am to 4pm is spent doing activities within the department, and Friday includes a student presentation detailing their camp experience to their families. The week-long camp currently costs $1500, and financial aid is available to families demonstrating financial need. Students are asked to submit their transcripts and answer the following two questions: (1) What are two goals that you would like to achieve at camp? (2) What problem would you like to solve? Admission decisions are based on students' academic achievements and demonstrated interest. The College of Engineering outreach program coordinates the program promotion, student selection, housing, meals, and staff hiring for each program, which greatly simplifies the demands on the individual academic departments. Night counselors (typically undergraduate engineering students) take over at 4pm, and fun activities and outings are planned for students during the evening hours. The students stay in on-campus dormitories and eat in the university dining halls.

During 2023 and 2024, the chemical engineering camp was led by a faculty member and a post-doctoral researcher as well as two graduate student TAs who connected with students throughout the week to provide mentorship and identify student interests and career goals. The College outreach program paid the salaries of the graduate teaching assistants and the post-doc, and the teaching faculty member was a 12-month employee, so no additional funds were needed for the director's salary. The College outreach program had an extensive stockroom of everyday supplies (e.g. cardboard, yarn, paper plates, graduated cylinders, batteries, diapers, gravel, etc.) that the department was able to "shop" for free to provide materials for hands-on activities, such that the cost to the department was minimal. Prior to camp, the graduate teaching assistants and the director completed training in working with minors as well as attended an orientation meeting where safety expectations and processes were reviewed.

## Activities and Content

The daily themes are organized to introduce students to engineering design and the chemical engineering major before exploring chemical engineering topics at a deeper level. A chemical engineering camp workbook, developed by the departmental camp directors, is provided to each camper, and an instructor book is provided to all camp leaders. The workbook contains a colorcoded schedule of the week, maps of the applicable university buildings, safety protocols, and activity pages. The activity pages include an introduction to the day's theme and a worksheet for each activity. These worksheets serve as a workspace for design ideas/brainstorming. The instructor workbooks include additional pages with instructions for each activity to aid leaders. An example of the activity worksheet and the corresponding instructor guide is provided under the description of the pasta separations activity (Figures 1 and 2).

Day 1: Engineering Design

The day begins with a brief discussion about design trade-offs regarding cost, efficiency, quality, etc. and how different industries may have different priorities. For example, a pharmaceutical company prioritizes purity while a textiles company may prioritize sustainability. The Day 1 activities are described below:

- Balloon towers
  *Learning Objective: Apply engineering design principles; practice teamwork.*
  In groups of four, students design and build towers out of balloons and tape. Students are encouraged to discuss with their team whether they want to prioritize tower height, stability, or cost. Building supplies and extra build time have an associated cost, and students calculate their tower expenses at the end. Towers are judged and prizes awarded for the highest tower, most stable tower, and cheapest tower.

- Process design of ice cream production
  *Learning Objective: Interpret simple process flow diagrams; incorporate engineering economics in design problems.*
  Students are introduced to process flow diagrams and common process equipment. A flow diagram of an ice cream production process is provided with three "blank" unit operations students must fill in. They can also customize their ice cream production line by choosing the flavors/mix-ins and giving their ice cream flavor a fun name. Upon completion of the flow diagram, students must "purchase" the needed equipment by looking at a pre-made equipment catalog that has a simplified listing of different models of each piece of equipment and its cost. When a student "purchases" a piece of equipment, they receive a folded card with an outcome written inside that can add additional expense. For example, some models end up leaking: "Major leak! Loss of $1400 in revenue due to delays during clean-up." Some funny (but realistic!) outcomes are also included, such as, "This equipment does not fit through the door (who forgot to measure the door frame before ordering??) Hire a contractor to expand the door so equipment can be moved in for $1500." Some models experience no major problems and do not have any further expenses. After students total their overall expenses, ice cream is provided, and the team with the lowest cost gets first choice of flavors! For future camps,

we are exploring the option to have students tour the on-campus ice cream production facility in the Food Science Department.

- What it is like to be a chemical engineering major: undergraduate student panel and campus scavenger hunt.
  *Learning Objective: Identify the core topics of the major and hear about student experiences.*
  Camp leads briefly talk about the different topics covered within the undergraduate curriculum (process design principles, thermodynamics, transport phenomena, kinetics, process control) before a panel of undergraduate students discusses how they customized the ChE program to fit their interests and answers any questions campers have about their experience. In previous years, lab tours were included to show students the kinds of work and resources available to chemical engineering majors, but student engagement during these tours was often low and unfocused since the lab tours involved passive observation of equipment and listening to a grad student describe it. Instead, students now get to explore the engineering campus and see labs by completing a scavenger hunt in groups led by at least one camp leader. This has promoted greater engagement and also allows groups to explore areas of personal interest.

The remaining days have focused themes to demonstrate various fields chemical engineers can pursue after graduation. It is emphasized, however, that chemical engineers are not limited to these fields, and there are lots of opportunities!

Day 2: Polymers

The day begins with a brief introduction of polymers and having students identify as many items made from polymers in the classroom as they can.  Day 2 activities are described below:

- Diaper dissections: superabsorbent polymer testing
  *Learning Objective: Explore and identify the advantages of functional polymers and relate engineering design principles to an everyday product.*
  Students are given regular diapers as well as “swim” diapers and asked to consider what design elements they would prioritize for each product. Students are then allowed to cut open and make observations about the inside material in each type of diaper. They then measure how much water an intact regular and swim diaper can absorb (finding that, as expected, the regular diapers absorb a lot of water, whereas the swim diapers do not) and repeat the experiment using salt water. Students should find that the diapers cannot absorb as much salt water. This leads to a discussion that when testing diapers, it is important to use a liquid with similar properties to urine (like salt water) since the

electrolytes decrease the polymer absorbency.

- Self-folding polymers
  *Learning objective: Explore and experiment with self-folding polymers, a smart material.*
  Polystyrene sheets shrink when heated, and if only part of the sheet is heated, the sheet can be made to self-fold. This is most easily accomplished by drawing lines with a black permanent marker and exposing the sheet to IR light [11]. Students are shown how a polystyrene sheet can be made to self-fold into a cube, and then given polystyrene sheets, markers, and scissors to make their own self-folding designs. Students are asked to predict what shape their design will fold into before a trained camp leader heats it under the IR light.

Day 3: Separations and Sustainability

The initial discussion introduces students to the importance and prevalence of separations in processes. Students are asked to brainstorm separation methods they have used, such as a colander to strain pasta, filters in a coffee maker, sugar crystals separating from water when making rock candy, etc.  Day 3 activities are described below.

- So many pasta-bilities: pasta separation
  *Learning Objective: Identify properties that can be used in separations processes; plan and execute a project based on selected design priorities.*
  Each pair of students is given a large plastic bag containing a mixture of dry pastas of varying size and shapes (spaghetti, rotini, shells, rice, etc.) and challenged to design a separation process using common craft supplies (paper cups and plates, pipe cleaners, foam sheets, etc.). Their designs are judged based on the value of recovered product, where the value is based on the pasta type and purity. A table of values, including the "selling price" of each pasta product based on its purity, is provided to students at the start so they can choose their design priorities. An example of the activity worksheet for this activity is provided in Figure 1, and the corresponding instructor guide follows in Figure 2.

[redacted]

Day 3: Separations

## Design Challenge: so many pasta-bilities

**Project Name**

**Team Design Priority**

**Design Sketches**

| Product | Selling Price (per ml) Low purity | Selling Price (per ml) Moderate purity | Selling Price (per ml) High purity | Volume (ml) | Total Selling Price |
|---|---|---|---|---|---|
| Rice | 1¢ | 2¢ | 3¢ | ____________ | $ ____________ |
| Shells | 1¢ | 3¢ | 11¢ | ____________ | $ ____________ |
| Spaghetti | 1¢ | 2¢ | 6¢ | ____________ | $ ____________ |
| Rotini | 1¢ | 3¢ | 6¢ | ____________ | $ ____________ |
| | | | | **Total Revenue:** | $ ____________ |

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**Figure 1: Sample page from the student workbook for the pasta separations activity.**

[redacted]

Day 3: Separations

## Design Challenge: so many pasta-bilities (pasta separation)

Designed for twelve teams of 2

INSTRUCTOR GUIDE

### SUPPLIES

- Lots of various craft supplies (paper plates, envelopes, pipe cleaners, etc.)
- Scissors/Tape for each team
- 48 plastic cups with measurement markers ("product" cups: 4 per team)
- 3 boxes of each of (a) spaghetti, (b) rotini, (c) medium shells, and (d) orzo (or rice)

### SETUP

- Prepare pasta mixture for each team, making sure each team's mixture has the same amount of a given pasta.

### ACTIVITY

- Rather than design cost, this activity prioritizes separation performance and product revenue. Teams have roughly twenty minutes to design/test their separators, but only **five minutes to actually separate their materials into the product bowls to be measured/sold.**

- Remind students that each pasta has different selling prices based on its purity. Allow teams to decide their own design priorities (separating a lot of a pasta vs achieving a high purity) but remind them they only get FIVE MINUTES to separate their mixtures.

- Announce three possible awards:
  - Most revenue
  - Highest purity product
  - Best style

- After separation, have leaders judge purity (low, moderate, high) so students can calculate revenue.

- **Post-activity discussion:** what were some challenges? Why didn't your process work as well as you thought it would? What attributes of the pasta was used in the separation process? What attributes could you use for chemical species?

- **RULES**:
  Teams may design a single separator device or several stages (separate devices) to achieve separation, but no more than four stages/devices allowed.

  Pasta may be processed in batches if the whole mixture does not fit in the separator.

  Design engineers may not touch the actual pasta, nor use any of the materials as chopsticks to separate pastas, but engineers may hold/shake/stir their device or pour pasta from one device to another, etc.

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**Figure 2: Sample page from the instructor workbook for the pasta separation activity.**

- Mini wastewater treatment plants
  *Learning objectives: Demonstrate the role of separations in sustainability and environmental and public safety.*
  This activity is adapted from that described in [12]. Students watch a short video [13] about how wastewater plants operate and the present and future challenges in the field. They are then tasked with purifying water contaminated with things like soil, dish soap, oil, coffee grounds, and sand. They are provided with a 2-liter soda bottle that can be cut in half such that the top half can be turned upside down (like a funnel) and fitted onto the lower half. Their separator device is made in that top section, and the contaminated water is poured into it such that the treated water is filtered into the lower half. Students can use different combinations, thicknesses, and sequences of sand, gravel, and different types of cloth (mesh, cotton, felt) to make their separator. A Secchi disk is used to measure the initial and final turbidity of the water. Students find that using too much filtration results in a slow separation process but using too little results in poor separation and treatment.

Day 4: Biomanufacturing

The Chemical and Biomolecular Engineering department partners with the biomanufacturing facilities on North Carolina State University's campus to give students an opportunity to practice lab skills.

- A glowing experiment: recovery of green fluorescent protein (GFP)
  *Learning Objective: Practice separation methods common to biological materials, such as chromatography and centrifugation; practice proper lab safety protocols.*
  After a tour of the biomanufacturing facility during which students see both upstream and downstream processes, students complete two experiments focused on purification of biological materials during which they recover GFP using either chromatography or centrifugation. Students determine the success of their separation by observing fluorescence of the GFP under UV light. Students get to practice common lab techniques, such as pipetting, as well as practice proper safety protocols when working in the lab.

Additional Activities Throughout the Week:
- **Panels**: To better illustrate the diverse fields chemical engineers pursue, campers have a chance to interact with a panel of graduate students and a panel of alumni working in industry. These panels are very casual and interactive, so students are encouraged to lead the discussions in directions of interest.
- **Icebreakers:** At the start of each day and after lunch, the camp TAs lead icebreaker activities as a way to build community and social interaction among students. These icebreakers change each year, but example activities include:

    - Five Minute Masterpiece - teams of four are each provided a printed version of a famous painting and given five minutes to recreate it on a large piece of paper using colored chalk.
    - Find Your Pair - a piece of paper with a word is taped to each student's back. Each word has a "pair" (for example, "peanut butter" and "jelly") and students are challenged to find their pair by asking only yes or no questions to figure out their own word.
- **Parent Presentations:** On Friday morning, students give a presentation to their parents. Students are grouped in pairs, and each pair selects an activity from the week and creates a slide to present for about two minutes.

**Assessment**

Assessment of each camp is conducted by the COE's outreach program rather than individual departments. This ensures that the assessments across all camps follow appropriate data collection and storage protocols. The primary method relies on surveys in which students are asked whether they "strongly agree," "agree," "disagree," or "strongly disagree" to several statements. These surveys are completely anonymous and voluntary. Because these assessments are done for the sole purpose of camp improvement and no identifying information has been collected, ensuring anonymity, the University's Institutional Research Board (IRB) office confirmed no IRB protocol was needed but provided guidance on appropriate methods.

The results for the camps in 2023 and 2024 are organized in Table 1. Overall camp perceptions, as indicated by the percent of campers who submitted the survey indicating they "strongly agree" or "agree" with the statement "Overall, I enjoyed my workshop" is shown in Figure 3 for years 2011 to 2024. This data indicates an upward trend and reduced variability starting in 2018, when the camp switched from the singular, week-long fuel cell car project to several shorter activities organized into themed days. While a longer project allows greater depth and complexity, the current structure allows exploration into a variety of engineering applications, so activities resonate with a greater number of students' interests.

**Table 1: Percent of campers who submitted the survey indicating they "strongly agree" or "agree" with each statement.**

| | 2023<br>N=24 | 2024<br>N=21 |
|---|---|---|
| My instructors were knowledgeable. | 100% | 100% |
| I had opportunities to ask questions and engage in discussions. | 100% | 100% |
| My workshop was interesting. | 100% | 100% |
| Activities were engaging. | 96% | 90% |
| My workshop broadened my understanding of the work that engineers do. | 100% | 100% |
| My workshop had the right amount of activities. | 100% | 81% |
| Failure is an important part of successful problem solving. | 100% | 100% |

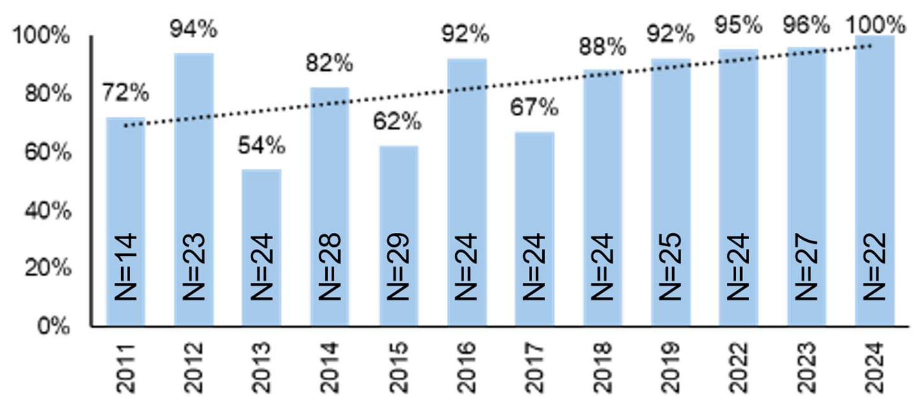


**Figure 3: Percent of campers who submitted the survey indicating they "strongly agree" or "agree" with the statement, "Overall, I enjoyed my workshop." The total number of survey submissions is included within the plot. Note: The residential camp was not held in 2020 and was virtual in 2021 but not surveyed.**

Students were also asked for any comments regarding camp. Positive comments confirmed the camp achieved its goal to help inform high school students of the variety of applications and opportunities of chemical engineering. Example comments (all taken from the 2024 camp) are included below:

> "*Having sessions with past chemical engineering majors was very helpful because they helped me understand what being a chemical engineer truly means and what they do in a lab or industry environment.*"

> *"This workshop had extremely good leaders and TAs. They were happy to talk about their own experiences and answer questions any time. They made the camp fun and entertaining with ice breakers and engaging activities, but also conveyed a lot of information."*

> *"Most of the concepts (ex: water filtration) were covered in far more depth than my high school classes."*

These comments emphasize the importance of faculty and alumni involvement. Students appreciated interactions with engineers of various experiences and backgrounds.

Comments for suggestions and improvements focused on more activities:

> *"I wish we did more labs and got to learn more about engineering and do more like we did when we did the thing at [the biomanufacturing lab]."*

> *"I enjoyed it overall but wish it was a little more in depth at times."*

These comments highlight several challenges in meeting student expectations. While adding more activities is a common suggestion, the schedule must balance the number of activities and the amount of time needed to allow the depth students seek in this type of environment. Additionally, as students are of varying ages and come with varying academic preparation, activities must be accessible to a wide audience. While some activities may have been technically challenging for some students, other students may have found them too simple. To help address these comments, future activities will incorporate opportunities to "modify and improve" projects for students who complete their first designs quickly.

These surveys provide a general overview of student satisfaction, but future assessments could include activity-specific questions to help directors identify areas for improvement and align activities with student interests.

## Summary

Outreach programs play an important role in recruitment, especially for students unfamiliar with specific fields like chemical engineering. Summer camps provide a fun but educational opportunity for students to better understand career paths associated with chemical engineering degrees. Early exposure to the field can help students identify their own interests so they are better prepared to choose their college and major. The activities discussed here have been used for several years to effectively demonstrate the broad range of chemical engineering applications. Challenges associated with serving students of varying ages and academic backgrounds remain, and camp activities and schedules will evolve to better meet the changing needs of students.

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