Education Strategies to Address the Looming Shortage of ChemEs

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During the next decade, the number of chemical engineering graduates is expected to decrease by 38% while demand increases by 10%. This dilemma can be addressed by improving our education strategies.

By supplying raw materials and fuels to almost every industry, chemical engineering is vital to the domestic economy. The chemical process industries (CPI) are undergoing an energy transition — a process that will continue for 50 years or more — to decarbonize traditionally carbon-heavy processes and thereby address climate change *(1–5)*. Because chemical engineers will play a critical role in the energy transition, the federal government projects that demand for chemical engineers will grow by 10% over the next decade *(6)*. This is faster than many other engineering disciplines and jobs in general.

For many decades, the graduation rate of chemical engineers has oscillated in a sinusoidal pattern with a period of about 20 years. Unfortunately, we are currently on the downside of the curve, and the production rate of chemical engineers is expected to decline by 38% during the next decade. Despite the overall decline, it is possible to buck the trend. This article shares some educational practices implemented at Texas A&M Univ. that have helped improve the production of skilled BS chemical engineers and may address this looming shortage.

The vital role of chemical engineers

Table 1 summarizes the industries where chemical engineers play vital roles. In addition to these industries, students apply their work ethic and problem-solving skills in numerous other fields, such as banking, real estate, business, teaching, and programming. Furthermore, some also pursue advanced degrees in business, law, and medicine. Because of our foundations in all three sciences, mathematics, engineering, and economics, it is often said, "With a chemical engineering degree, you can do anything."

As shown in Figure 1, the U.S. economy has undergone two previous energy transitions: from wood to coal (1850–1900) and from coal to oil and gas (1910–1960). Each of these transitions required about 50 years. Thus, the new generation of chemical engineers can expect to spend their entire careers in the energy transition, transforming our economy.

Chemical engineers are playing a vital role in the energy transition through the following activities:

- improving the efficiency of energy and materials
- replacing fossil fuels with biofuels, hydrogen, and nuclear energy

• increasing energy storage efficiency and deployment
• electrifying transportation and industrial processes
• capturing carbon dioxide from fluegases and the atmosphere, sequestering it underground, and/or transforming it into value-added products.

The U.S. Bureau of Labor Statistics projects that the demand for chemical engineers will increase by 10% by 2033, which is greater than other engineers (9%) and jobs in general (4%) *(6)*. Their projection is based on the need to replace retiring baby boomer engineers, but also the growing environmental and sustainability concerns that have led chemistry and manufacturing firms to hire more chemical engineers. In addition, demand for these workers will increase with chemical engineering's migration into nanotechnology, alternative energies, biotechnology, and other fields.

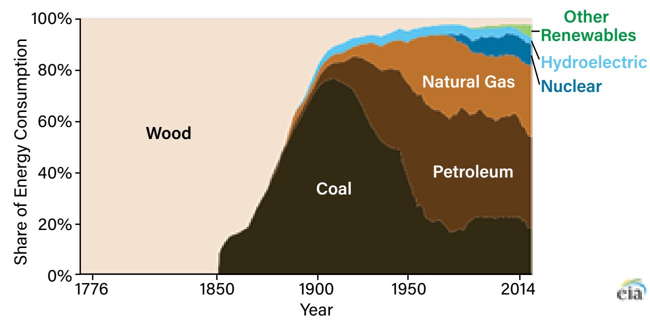
The looming shortage of chemical engineers

Figure 2 shows the historical fluctuations in the U.S. production of BS chemical engineers from 1960 to the present. The most recent data from 2023 indicate that the production is at 69% of the peak. The solid line connecting the four troughs has a positive slope, reflecting the growing population and economy. Since peaking in 2018, production has followed a downward trend. Assuming the same oscillatory patterns continue, it appears that production of BS chemical engineering graduates will reach a minimum of approximately 5,000 per year in 2031 compared to 8,034 per year in 2023. This decline of ~38% will occur while the Bureau of Labor Statistics projects an increased demand of ~10% during the same period.

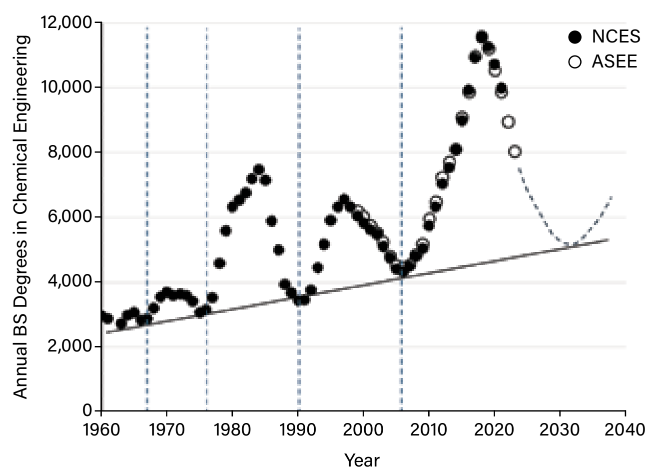
Figure 3 shows the annual production of BS chemical engineers from Texas A&M Univ. Although it also follows a cyclical pattern that aligns with national production (Figure 2), the recent oscillation is dampened significantly. For example, the 2023 production is 92% of the peak, vs. 69% nationally. The following discussion provides background information about Texas A&M Univ. and how it has been able to defy the declining trends.

Table 1. The following industries have a strong chemistry component and are major employers of chemical engineers.

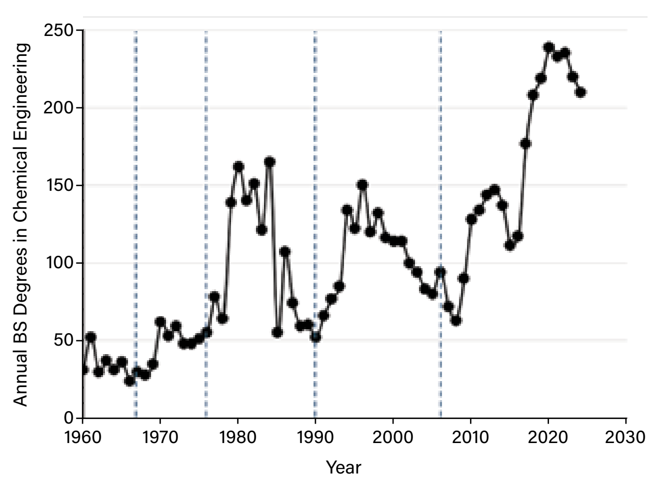
Industrial Sector	Example Industries
Energy	Oil and gas production, oil refining, natural gas processing, coal processing, biofuels, power plants
Chemicals	Commodity chemicals, fertilizers, fine chemicals
Materials	Cement, ceramics, glass, metals, polymers, cosmetics, nanotechnology
Biotechnology	Pharmaceuticals, paper/pulp, food, brewing
Electronics	Semiconductors, batteries
Transportation	Automotive, aerospace
Environment	Water purification, gas scrubbing



▲ **Figure 1.** The diagram illustrates the share of energy consumption in the U.S. from 1776 to 2014. Source: Adapted from *(7)*.



▲ **Figure 2.** The graph shows the historical production of BS chemical engineers in the U.S. Vertical dashed lines mark the local minimum in national production. The data were gathered from the U.S. National Center for Education Statistics (NCES) *(8)* and the American Society for Engineering Education (ASEE) *(9)*.



▲ **Figure 3.** The graph shows the historical production of BS chemical engineers from Texas A&M Univ. Vertical dashed lines mark the local minimum in national production shown in Figure 2.

Chemical engineering at Texas A&M Univ.

Founded in 1876 as a land-grant institution, Texas A&M Univ.'s College Station campus is one of the largest universities in the country, with an enrollment of 72,560 students in 2025. Known for their strong work ethic, Texas A&M graduates are highly sought after by industry. Many graduates support diverse industries in Houston (energy, chemicals), Austin (semiconductors, software), and Dallas (aerospace, finance).

Most Texas A&M undergraduates are from Texas and are typically drawn from the top 10% of high school graduates. Because the quality of high schools varies dramatically, so do the abilities of the incoming students. Its high percentage of Hispanic engineering graduates (24%) *(10)* establishes Texas A&M as a Hispanic-serving institution.

The Dept. of Chemical Engineering was founded at Texas A&M Univ. in 1940 *(11)*. In 2023, it produced the largest number of BS graduates in the nation (Table 2). With starting salaries that are the second highest in the nation (Table 3), the department is well regarded by industry for producing large numbers of high-quality graduates.

Curriculum. The current curriculum (Table 4) is designed to transform "raw" incoming students into "refined" engineers with skills that serve industry. Unfortunately, to comply with state mandates, the number of credit hours has been reduced over the years. This has forced our department to remove the following courses from our curriculum: statics and dynamics, electrical engineering, statistics, engineering ethics, analytical chemistry, and chemistry laboratories. A key challenge is to maintain quality within the constraint of the reduced credit hours; thus, the curriculum must be more efficient.

Table 2. The following universities graduated the most BS chemical engineers in the U.S. in 2023 *(9)*.

University	Annual Graduates
Texas A&M Univ.	239
Georgia Institute of Technology	170
The Ohio State Univ.	155
Univ. of Texas at Austin	155
Univ. of California, Berkeley	149
Purdue Univ.	147
The Pennsylvania State Univ.	139
Yale School of Engineering & Applied Science	130
North Carolina State Univ.	129
Arizona State Univ.	124

Table 3. The following table lists the highest reported starting salaries for BS chemical engineers in 2020 *(12)*.

University	Annual Starting Salary
Rice Univ.	$80,100
Texas A&M Univ.	$79,900
Univ. of Texas at Austin	$78,400
Massachusetts Institute of Technology	$78,200
Cornell Univ.	$77,500

Foundational engineering courses. At Texas A&M, the College of Engineering teaches freshman cross-disciplinary foundational engineering courses. Traditional engineering courses (*e.g.,* thermodynamics, fluids, heat transfer, reaction kinetics) have well-established, stable content. In contrast, there is no universal agreement on the content of freshman engineering courses. As a result, over the decades, many educational models have been tried and abandoned.

One of the freshman education models was derived from the Foundation Coalition (FC), a large NSF-funded project designed to transform engineering education. Although this model is no longer used to teach freshman engineers at Texas A&M, key features of the FC model follow:

- it integrated with other freshman courses, such as physics, mathematics, and chemistry
- it integrated with upper-level engineering courses by laying a solid foundation
- it used projects to motivate engineering design
- it used computers extensively
- it utilized "engineering accounting" (discussed later) to frame problem solving.

Controlled studies have documented the positive impact of this FC-derived curriculum on the education of chemical engineers *(13, 14)*. For example, grades in the mass and energy balances course improved by 0.45 points — almost

Table 4. The following courses are part of the chemical engineering technical curriculum at Texas A&M Univ., not including humanities or electives.

Sciences	Mathematics
General chemistry	Calculus
Organic chemistry	Differential equations
Physical chemistry	
Mechanical physics	**General Engineering**
Electromagnetic physics	Computation
Chemical Engineering Core Courses	
Mass and energy balances laboratory	Reaction kinetics
Mass and energy balances	Materials
Thermodynamics I	Safety
Thermodynamics II	Controls
Numerical analysis	Bioprocess engineering
Technical writing	Chemical process industries
Fluids	Unit operations laboratory
Mass transfer	Process economics
Heat transfer	Plant design

half a letter grade. Failures (D, F, and Q-drop) in mass and energy balances decreased by a factor of 2.6. Upon graduation, overall grade point average (GPA) increased from 3.16 to 3.40.

These dramatic results underscore the importance of providing a solid foundation that supports upper-level classes! Unfortunately, due to various changes in the freshman engineering program, the FC curriculum is no longer taught. The next sections discuss how the sophomore curriculum has advanced by implementing some of the lessons learned from the FC model.

Addressing the looming shortage of chemical engineers

The annual production of skilled chemical engineering graduates is determined by the following simple formula:

$$SCE = RR \times f_R \times f_Q \quad (1)$$

where *SCE* is the number of skilled chemical engineering graduates (people per year), *RR* is the recruiting rate into chemical engineering departments (people per year), f_R is the retention of students within chemical engineering departments (fraction), and f_Q is the quality (fraction). "Quality" describes graduates with sufficient skills to be productive within the chemical industries described in Table 1. Although there is no exact definition of quality, many recruiters in the chemical industries will only interview students with a GPA of 3.0 and above. Generally, students who graduate with less than this GPA find employment in other industries.

To meet the future needs for skilled BS chemical engineers, all three terms (*RR*, f_R, and f_Q) must be increased.

To improve the annual production of skilled chemical engineers, specific steps taken at Texas A&M Univ. are described below:

Retention (f_R). Despite our rigorous curriculum (Table 4), about 85% of students who enter our program graduate with a BS degree in chemical engineering. This compares favorably to another Hispanic-serving institution, which has 41% retention within chemical engineering *(15)*. Felder *et al.* showed that active and cooperative learning increases retention (f_R) from 68% to 85% *(16)*. Because students in our department commonly work in teams, this cooperative learning model helps explain our high retention.

Entry to major (RR). Historically, students at Texas A&M were accepted directly into specific engineering departments, which allowed for customized freshman-year coursework. However, in 2015, the College of Engineering changed its admissions policy. Now, freshmen are accepted into the college, not a specific department. Before their sophomore year, students select their engineering discipline through an Entry to Major program. This new approach has both advantages and disadvantages:

- *Advantages*. To explain the benefits of a chemical engineering degree, our department makes a highly compelling "pitch" to freshman engineers. In contrast, high school counselors generally are not familiar with chemical engineering, so many high school students do not even know chemical engineering is an option. These pitches greatly increase *RR* in Eq. 1, and they are a major factor in producing large numbers of graduates.
- *Disadvantages*. It is no longer possible to offer FC content to freshman chemical engineers, which can make it more difficult to prepare them for success.

Curriculum review (f_Q). Recently, our department underwent a three-year curriculum review under the tutelage of the Texas A&M Center for Teaching Excellence. This formal process queried stakeholders (current students, past students, employers, and faculty) about the curriculum and identified major deficiencies in our program resulting from the loss of FC content in the freshman year. To overcome the identified deficiencies, a laboratory was added to accompany the traditional mass and energy balance course. The ultimate objective is to improve student success, which will increase f_Q in Eq. 1.

Mass and energy balance laboratory

The mass and energy balance laboratory is designed to be the first course in chemical engineering. For example, it can be taken by freshmen who are contemplating entering chemical engineering. More commonly, it is taken by sophomores in parallel with mass and energy balances, a lecture course that historically was the first introduction to chemical engineering. The topics in the laboratory align with the lecture and are designed to reinforce the lecture content.

In science, technology, engineering, and mathematics (STEM) education, introductory courses are often labeled as "weed-out" classes designed to separate the strong from the weak. By contrast, this laboratory class is designed to lay a solid foundation so students can succeed in their upper-level classes. Large portions of the course are taken from the FC material previously taught in the freshman year, which was proven to enhance student performance *(13, 14)*.

The course incorporates active and cooperative learning, which increases retention *(16)*. The students work in teams (cooperative) on in-class exercises (active). Roughly half of classroom time is spent on in-class exercises, with the remaining half devoted to lecture material.

Because the course lays a foundation for success in future courses, it is essential for students to strive for mastery. For those students who are bright and come from excellent high schools — about 30% of the students — mastery comes easily to them; the remaining students struggle to achieve mastery. To help them, a bonus exam is offered after each regular exam. The bonus exam has similar questions to the regular exam, so students who carefully study the solution to the regular exam can earn bonus points that improve their grade. This approach allows students to be challenged and fail, but it also helps prevent them from becoming discouraged. In the face of adversity, keeping students motivated is the key to success.

In addition, some students enter the laboratory course with bad habits and attitudes from high school. We help them shift toward a more professional attitude that will serve them well in industry.

In some ways, the laboratory is a "catch-all" class, meaning it covers topics that do not fit neatly into upper-level classes. For example, because of the reduction in credit hours, the laboratory covers topics (statistics, statics and dynamics, electrical engineering, and engineering ethics) that were abandoned from the curriculum. The major themes of the laboratory course include:

Computer tools. The students learn Excel and Visual Basic for Applications (VBA), an embedded programming language. To enhance their visualization skills and design abilities, students learn Fusion 360, a 3D modeling program.

Unit conversions. Students are well-familiar with the SI system, which they first learned in high school physics and chemistry. They are less familiar with the American Engineering System (AES) and other traditional units often derived from the English system. Proper use of units is emphasized strongly, particularly the conversion factor g_c, which is often confused with the acceleration from gravity g.

Basic physics. Many students are attracted to chemical engineering because of their love of high school chemistry. However, students are often less comfortable with physics. Principles from physics are emphasized because of their strong role in chemical engineering, which historically was derived from mechanical engineering.

Problem solving. Creative approaches to problem solving are taught and emphasized through repeated exercises.

Communications. Students are taught how to write technical reports, with particular emphasis on proper communication and use of tables and graphs.

Dynamic systems. Students model dynamic systems: *e.g.,* water-filled tanks, spring-mass-damper systems, and resistor-capacitor-inductor systems. In an approachable manner, they are introduced to differential equations, which are solved both analytically and numerically.

Statics and dynamics. In past years, students had an entire course on statics and dynamics. Because credit hours are reduced, highlights of this topic are presented.

Electricity. In the past, students had an entire course on electrical circuits, but this is no longer required because of reduced credit hours. The basics of electricity and circuits are presented. Emphasis is placed on semiconductors, a growing industry that is likely to employ more chemical engineers in the future.

Statistics. Because a full course in statistics is no longer required, key concepts from descriptive statistics are taught.

Ethics. Previously, a full course in engineering ethics

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was required, but when this was abandoned, ethics was infused into the curriculum, including this laboratory class.

Thermodynamics. Students are introduced to the first and second laws of thermodynamics, as well as foundational concepts such as work, heat, and heat capacity. Heat is energy flow across the system boundary driven by a temperature driving force. Work is energy flow across the system boundary driven by any other driving force.

Rate processes. Four rate processes are described: fluid flow, heat, electricity, and diffusion. The concept of flux (flowrate per unit area) is introduced. All rate processes are propelled by driving forces, which reinforces this concept introduced in the earlier thermodynamics topic.

Design. At a high level, engineering design is introduced. This prepares them for the capstone project of the laboratory: a rocket propelled by water and compressed air. Each student team creates a rocket from a 2-L soda bottle with fins, nozzle, and nose cone produced by 3D printing. The launch is very festive, with students vying to see which team reaches the greatest height. Each team submits a report that describes their rocket. This capstone project incorporates about 70% of the topics described above; thus, students realize that the seemingly disparate topics integrate into a coherent whole. The report requires teams to formulate a large VBA program that describes the rocket properties (*e.g.,* mass, pressure, height, velocity, and acceleration) during each phase of the launch. The project is too massive for one student to complete, so the importance of teamwork is reinforced.

Engineering accounting. Engineering accounting employs the universal accounting equation (UAE):

$$\text{Final} - \text{Initial} = \text{Input} - \text{Output} + \text{Generation} - \text{Consumption}$$

This equation is applied in a very systematic manner in which students must: define the system (a subset of the universe being evaluated by the engineer); define the time interval over which the accounting occurs; and define what is being counted. Counted quantities include mass, charge, linear momentum, angular momentum, energy, entropy, and money. If the quantity does not change within the universe, it is said to be conserved; if the quantity does not change within the system, it is said to be steady state. The UAE is foundational to rational thought, and it serves as an organizing framework for all engineering.

Closing thoughts

During the next decade, the demand for skilled chemical engineers is expected to grow by ~10% while the supply is expected to decrease by ~38%. To address this looming shortage, new educational strategies were implemented at Texas A&M Univ. that accomplish the following:

• increase recruiting rate through "pitches" that inform students about the benefits of chemical engineering

• improve retention using active and cooperative learning methods

• improve quality of graduates by adding a laboratory class to the traditional mass and energy balances course.

The primary goal of the laboratory class is to lay a solid foundation that allows students to succeed in their upper-level classes, and, ultimately, their careers. For those departments that wish to consider adding this laboratory to their curriculum, we are happy to share our course content. CEP

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