Specializations in Chemical Engineering Departments

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Abstract:

United States chemical engineering department heads and chairs were surveyed in spring and summer 2024 about specializations, such as minors, concentrations, and emphases. This included all departments with "chemical engineering" in their name. Out of the 43 responding institutions, 19% offer no specialization. Minors and concentrations are each offered by around 38% of departments, and other specializations are offered by 28% of departments. The most commonly offered minor and concentration is bio-related. The wide variety and number of bio-type specializations (bioengineering, biochemical, etc.) led to this result. "Other", with multiple pre-medicine specializations, was the next most prominent. Concentrations covered mostly different areas from the minors: biomolecular, computation/data science, sustainability, petroleum, premedical, and environmental. Other specializations overlapped minors and concentrations with other bio-related fields, environmental/sustainability, and pre-medicine/health but added categories of pulp/paper/bioresource and energy. Departments have added new minors in biomedical, chemical engineering, and materials engineering in the past ten years. They have also added data science/analytics concentrations and bio-related and environmental/sustainability other specializations. A few departments have removed materials and bio-related specializations.

Requirements to complete about specializations varied across the reporting institutions. Minors typically require about 17 credits, which is more than the 13 or so required by concentrations or other specializations. Students have on average 12 open engineering/technical/chemical engineering credits that they may use toward a specialization. Elective courses from the major may be double-counted as part of a specialization without restrictions at more institutions (72%) than required courses (33%). Departments are nearly evenly split on allowing undergraduate research and/or internships to count towards a specialization. Those who did allow research or internship credit frequently had quality requirements or a restriction to 1 or 2 semesters or 3 – 6 hours. Minors appear on the student's transcript at all responding institutions. Concentrations are transcripted at only half of the institutions, and other specializations at 40% of institutions. Approval is needed at the department level and commonly at college and university levels but not as often by a governing board, trustees, or regents (35% and lower). Concentrations require college and university approval at lower rates (50%) than minors and other specializations (70% and higher). Most institutions did not report restrictions on specializations, but two institutions reported that chemical engineering majors are not allowed to earn a chemistry minor.

Chemical engineering students complete specializations outside of the department, with chemistry and math the most common by a factor of two. Other specializations from outside the department were computer science, business, biochemistry, materials science, and other bio-related areas. The median for BS graduates completing a minor of any kind was 45% and about 30% for concentrations and other specializations, each. The specializations offered by the departments may be taken by more than chemical engineering majors, with an average of about

20 students per year completing minors and other specializations offered by the department and 28 per year completing concentrations.

Introduction:

To complement the ongoing series of "How We Teach" surveys [1] by the AIChE Education Division's Curriculum Survey Committee, this survey examines specializations (minors, concentrations, emphases, options, certificates, etc.) offered by chemical engineering departments and completed by students in chemical engineering departments. The How We Teach series recently surveyed the use of elective courses in chemical engineering departments [2]. Elective courses are commonly used by students to meet curricular requirements such as chemical engineering electives, engineering electives, technical electives etc. in the student's (major) degree program. However, elective courses and required courses may also be used by students to fulfill requirements for curricular minors, concentrations, emphases, certificates, etc. The term specializations will be used to refer to this collective group.

Specializations, historically minors, were used to complement the major chosen by the student for their degree field and these minors were used to demonstrate specialization within the major area of study (e.g., materials science with a chemical engineering major) or to broaden the area of study (e.g., computer science with a chemical engineering major). While less common, a minor might simply demonstrate the diverse range of skills and interest for a student (e.g., theater minor with a chemical engineering major). A minor is usually not included on a diploma, however, along with major, a minor is commonly included on the student transcript to demonstrate the additional effort by the student to complete the work. While a declared major is usually a requirement, a declared minor is optional.

More recently, other specialization terms have become more commonly used in academia for a variety of reasons. These terms include concentration, emphases, options, certificates, etc. Generically, a concentration is a subspecialty in a major field, an option is usually fewer credits than a minor, and a certificate is historically a postsecondary credential that is more focused on practical training and experience. However, these terms have more recently been broadened in meaning to fit the needs of the faculty, the students, and within the institution's governing requirements, the need to be approved or not approved at different levels in the university.

Lastly, electives, as previously surveyed, often play a large part in the courses that students take to complete a specialization. Thus, there is a connection between the two. Specializations are often viewed within a discipline as a way to demonstrate the ability of that major to lead to additional career paths (e.g., a pre-medicine major in chemical engineering), to advertise the collective expertise of the faculty (polymers), or to help a student show a commitment to a narrow part of the field (any of the bio-type specializations). The major is typically the basis of the profession, often evolving while maintaining its core focus; the specialization is a way to demonstrate change to show the applicability of the major to evolving fields, companies, and job descriptions. Thus, the list of currently offered minors can be viewed as the pulse of the profession. Specializations also become a tool to fill in schedules due to an extra semester needed to complete the program after taking an internship for one semester, for example.

While topics in chemical engineering such as mass and energy balances are surveyed periodically by the Curriculum Survey Committee[3, 4], a previous survey on minors does not appear to have been conducted. However, minors have been touched on in previous surveys in 2016 and 2024 as part of other surveys on the curriculum [5] or chemical engineering electives [2]. For a limited number of countries outside the United States, a similar study of specializations in chemical engineering programs was reported in 2006 [6]. Thus, chemical engineering departments were polled in Summer 2024 to obtain information about specializations. The goal is to learn more about the numbers of specializations, categories of specializations, general requirements for them, how they change over time, and what level of approval is required to approve these changes.

Methods:

United States chemical engineering department heads and chairs were surveyed in Summer 2024 about specializations, such as minors, concentrations, and emphases. This included all departments with "chemical engineering" in their name. A link to the survey questions in Qualtrics was sent to the AIChE Education Division's listserv for department heads and chairs in July 2024 with a reminder in August. The survey questions are given in Appendix A and included the following questions about specializations: credits required, approval levels required, appearance on the transcript, names, new and removed specializations, double-counting of credits, and restrictions. The survey also asked about the specializations students complete outside the department and specialization completion rates by chemical engineering majors and of specializations offered by the department.

Results and Discussion:

Responses were received from 43 institutions (Appendix B) out of approximately 160 institutions in the US with chemical engineering programs. 35 of 43 respondents (81%) indicated offering one or more types of specializations. This compares with 62% in 2016 and 67% in 2024 [2, 5]. 42% offered minors, 35% offered concentrations, and 28% offered "other" specializations (certificate, options, focus areas, specializations, tracks, and emphasis areas were used for this category). In addition, 45 total specializations were reported, averaging 1.3 types of specializations per department reporting at least one type of specialization. Nine schools offered two or more specializations (21%) and one school offered three different types of specializations.

The minimum number of credits required for minors ranged from 12 to 30 with an average of 16.3 (just over five 3-credit courses) and a mode of 15. The maximum number of credit hours covered the same range with an average of 17.2 credits (just under six 3-credit courses). For concentrations, the range was 9 to 15 credits, with an average of 12.4 and a mode of 12. As such, for this sample, a concentration is usually one fewer course than a minor. Lastly, the "others" ranged from 9 to 30 credits with an average of 12.3 but a mode of 9. Hence the "other" category essentially consists of three 3-credit courses. Determination of required credits for the specialization appears to correlate well with the terms: minors of 15-18 credits (5 to 6 3-credit courses) requiring the most additional coursework, concentrations being an intermediate average of 4 courses, and "other" typically having three courses. This clear difference in required

courses/credits may partially explain the decision by multiple schools (above) to offer two or more types of specializations as the student may be able to obtain the specialization that matches up with their interest in a subject or their credits available to complete a specialization (as a combination of chemical/engineering/elective credits required by the department, credits made available by general education courses completed throughout high school, and/or credits necessary to balance out an internship experience).

Departments reported an average (and median) of 12 credits of open engineering/technical/ chemical engineering credits in their programs that may be used to count toward a specialization. Typical students may then be able to earn a typical concentration or other specialization as described above without taking extra coursework. Earning a minor (16 to 17 credits) will require students at most institutions to take credit hours beyond those required for the major, which will be a hindrance in earning the minor.

Only six institutions reported institutional-level restrictions on specializations, giving students and departments a lot of freedom in this area. Two institutions do not allow their chemical engineering students to earn a minor in chemistry. Another allows students to earn multiple minors but only one emphasis. Two other institutions restrict double-counting to two or three courses. Another institution allows only two minors.

Total specializations reported in the survey are listed by focus area in Table 1. Based on the recent work looking at chemical engineering electives and how those authors grouped electives [2], we have chosen to use the same group names for the specializations: advanced core, bio-type, energy, materials, process-type, sustainability and "other". All specializations listed in the survey are show in Table 1 along with how they are grouped for this analysis. All specializations reported as currently offered by chemical engineering departments are shown by category in Figure 1. Based on the number of offerings, the elective group of "sustainability" would probably be better termed "environmental" when looking at minors. In addition, two of the minors in the sustainability group might also be sorted into the energy group. Otherwise, most of the minors were able to be grouped in relatively clear and independent groupings.

When comparing the size of the groupings in the electives survey versus this minor survey, there are some interesting comparisons. Similar to bio-type electives being offered the most widely offered (slightly more than materials electives and energy electives), bio-type specializations were also the most widely offered. In contrast, materials specializations were the smallest number of specializations. Advanced core electives map into no clear minors. With the very common offering of advanced core electives and undergraduate research also counting as an elective, it was surprising that there was not a single "advanced" chemical engineering minor offered such as graduate school preparation and only one example of a research focused specialization. In contrast to bio-type electives slightly leading energy and materials electives, bio-type specialization was clearly the most common specialization offered over "other" by 39%. Lastly, the "other" elective was the smallest category, while the "other" specialization was the second largest category.

Table 1. Names of specializations as reported by departments. Terms in parenthesis were different modifiers added to the base term. For example, specializations were titled: biomolecular, biomolecular engineering, and biomolecular science.

Bio-type:	Process:	Other:
• Biochemical (Engineering) • Biochemical Engineering and Bioprocessing • Bioengineering • Biological Engineering • Biomedical (Engineering) • Biomedical Eng. – Cell and Bioprocess Engineering • Biomanufacturing • Biomaterials and Biopolymers Engineering • Biomolecular (Engineering) (Science) • Biopharmaceutical Eng. • Bioprocess science • Biotechnology • Chemical engineering – Biological Engineering • Life Sciences	• Brewery Engineering • Chemical Engineering • Chemical Eng. Research • Chemical Process Eng. • Computation/Data Science • Computational • Computational Methods and Data Science • Computer Aided Chemical Engineering • Computer Science • Data Analytics • Data Science • Food Engineering • Image and Signal Processing • Numerical Methods and Computation • Paper Science • Pulp and Paper • Pulp, Paper, and Bioresource • Quality Science	• Applications of AI and Machine Learning • Chemistry • Entrepreneurship • Humanities • Interdisciplinary engineering • Management • Mathematics • Nanoscience • Nuclear Chemical Engineering • Pre-Law • Pre-medical (Pre-medicine) • Pre-Health Science
Energy:	**Materials:**	**Sustainability/(Environmental)**
• Energetics • Energy • Energy Engineering • Energy Production • Energy Systems • Petroleum Engineering • Sustainable Energy Technology	• Composites • Computational Materials • Materials Engineering • Materials Science • Polymers (Science) • Semiconductor Processing	• Energy, Environment, and Sustainability • Environment and Sustainability • Environmental (Engineering) (Science) (Chemical Engineering) • Environmental Chemical Engineering • Sustainability • Sustainability and the Environment • Sustainable Engineering, Energy, and the Environment

Figure 1. Total number of specializations offered (minor, concentration, other) grouped by type.

Chemical engineering specializations in a limited number of countries outside the United States (Great Britain, Ireland, Scandinavia, Australia, Canada), have also been surveyed [6]. Similar to the US, a wide variety of specializations are offered. In general, these specializations are similar to those in the US. Bio-type are again extremely common with environmental and sustainability also quite common. The biggest difference is in Great Britain and Ireland where Business/Management, International Study, and Languages also show up frequently. Obviously local concerns are also reflected in offering: fuel/energy (Denmark, Norway, Canada), pulp and paper (Finland), and pharmaceutical and fine chemistry (Sweden). With the exception of 'soft' options (international study, languages) offered in Great Britain, most of the other specializations are primarily 'hard' and directed towards chemical engineering, science, technology, and processes similar to the results of this study. While the combined results of this work and Byrne's work [6] cover significant world-wide chemical engineering programs, Central America, South America, Africa, Asia, and parts of Europe have not been surveyed.

Specializations added by departments over the last 10 years are shown in Figure 2 while specializations removed over that time are in Figure 3. Again, bio-type specializations led the way in specializations added (28% of the 43 specializations added). Process-type and other were the second most common specialization added. For specializations removed, materials led the way (42% of the 12 specializations removed). Comparing both figures, biotype specializations were a +8 in offerings, energy and materials were both net zero, sustainability was +2, while process-type and "other" led the way at +10 and +11, respectively. In the process-type specialization category, data analytics/science led with four additions. In the "other" category, pre-medicine was the largest contributor at three. The new and existing specializations in other

pre-professional areas (6 pre-medicine/health and 2 pre-law) show that departments perceive a need to offer these clearly defined specializations for chemical engineering students. The new data science specializations mirror the broad growth nationally in the university programs that offer a major/specialization in data analytics/science [7]. In addition, it is interesting to note that the pre-medicine and pre-law specializations are being offered through the chemical engineering departments. Since many students pursue these degrees with bachelors' degrees from the humanities (biological sciences [8] and political science [9], respectively), it is surprising that the home of the specialization is in the chemical engineering departments and not in the arts & sciences, arts & humanities, or the health sciences colleges/departments. However, the presences of these specializations show the desire for the chemical engineering departments to market themselves to attract these students to their programs [10, 11], that the profession feels it is a worthwhile pathway [12], and that the students find value in these specializations [13].

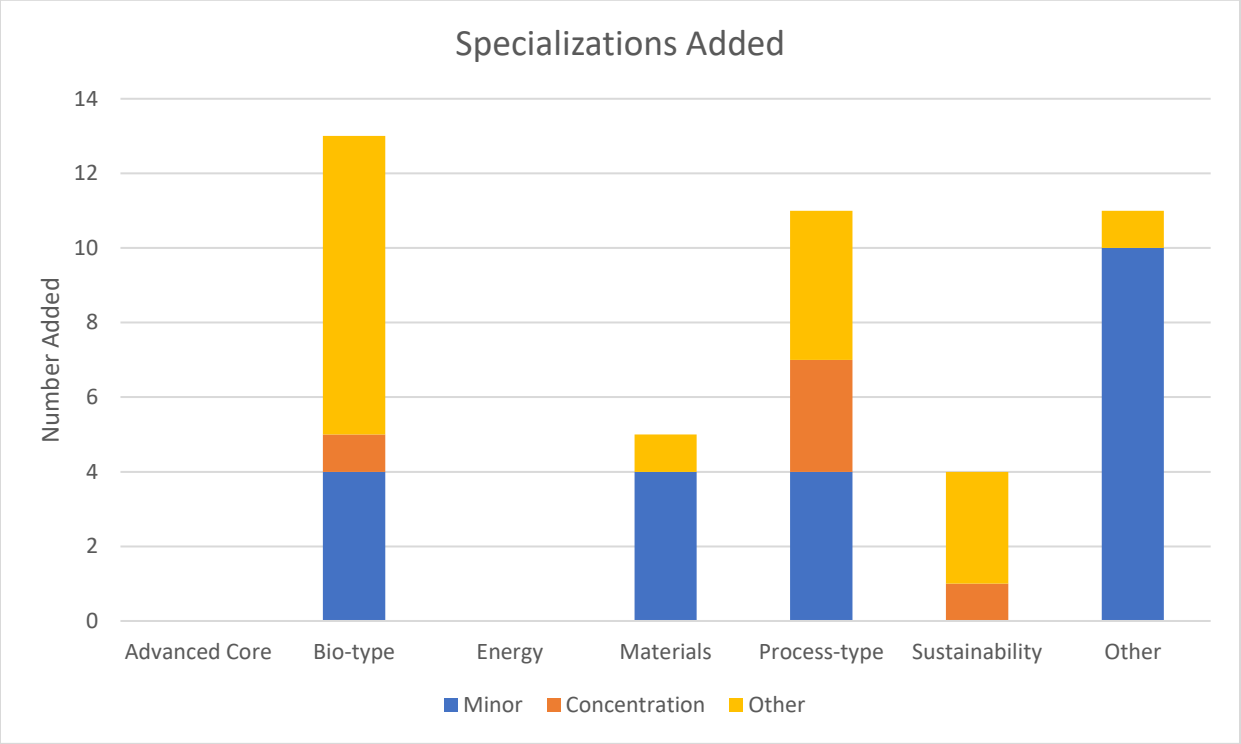

Figure 2. Specializations (minor, concentration, other) grouped by type.

Specializations within a department/degree program can also be viewed from the perspective of the department responding to trends in the discipline, general trends in engineering, or trends in student interests. Some significant trends in chemical engineering over the last few decades have included bio-type engineering, nano-science/engineering, and sustainability. Broader trends in academia have included forensics, data science/analytics, artificial intelligence, cybersecurity, and entrepreneurship. The bio-type engineering trend may be observed in the continual addition of bio-type specializations with the few losses possibly attributed to a separate bio-type department being formed and the specialization being moved to that department. Sustainability also shows specialization staying power. In contrast, nano-type specializations only have one

example in this data set. Of the broader trends in academia, data science/analytics seems to be making inroads in terms of specializations with four examples already offered in chemical engineering departments.

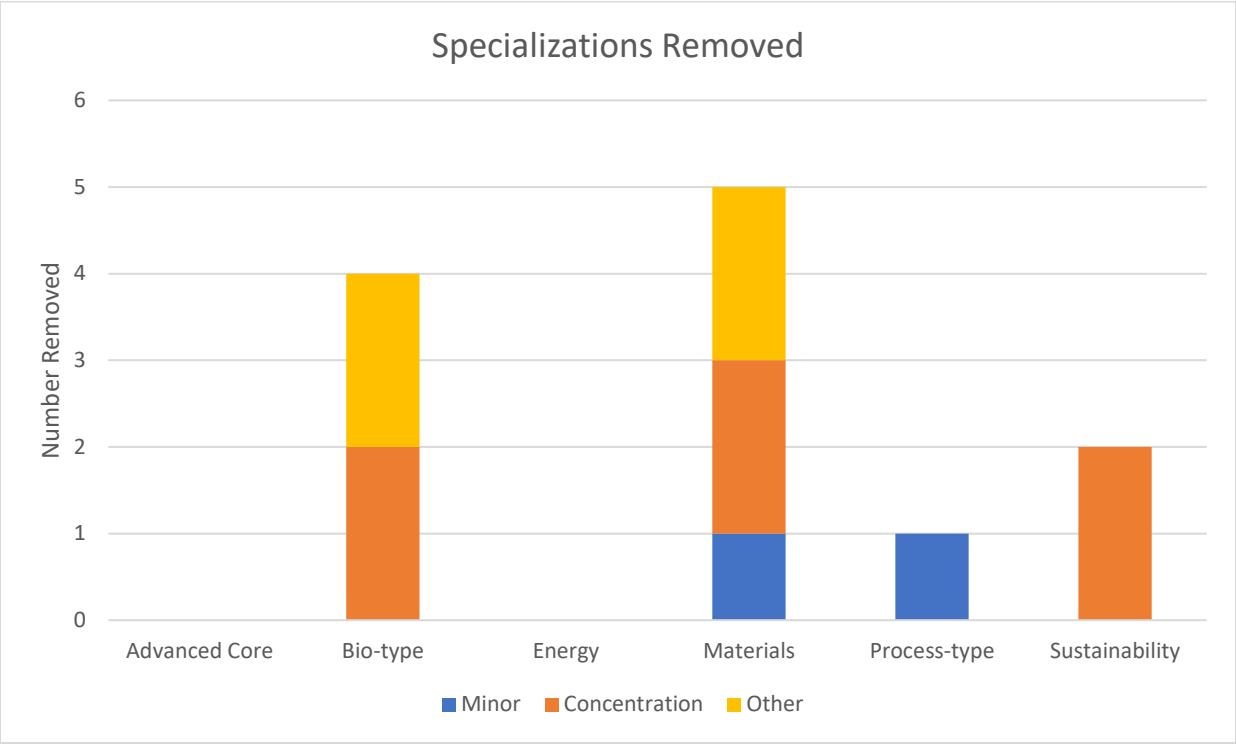

Figure 3. Specializations removed (minor, concentration, other) grouped by type.

Lastly, chemical engineering students often complete specializations offered outside of their home department. These specializations are shown in Figure 4. It is clear that the most common specializations outside the department are chemistry (16 total and 24%) and mathematics (16 total and 24%). The nine remaining categories complete the additional 50% of specializations outside the department. Multiple schools reported that the chemistry and/or math specialization can be obtained with no or at most one additional course beyond those required by the chemical engineering program. Consistent with the categories of specializations offered inside the department, common outside department specializations include biochemistry, bio-type, environmental, materials science, science/technology (food, packaging, pulp and paper, nanoscience, and data science). Honors and entrepreneur specializations also showed up in the other category.

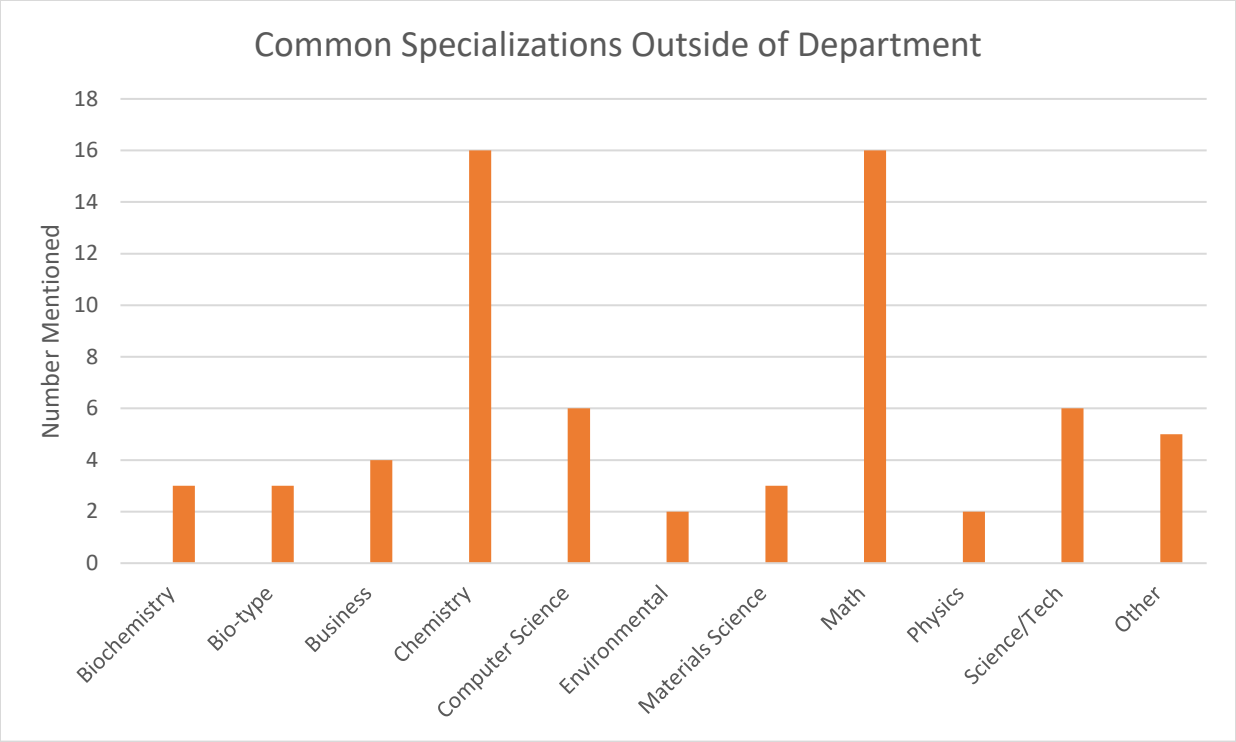

Figure 4. Common specializations completed by students outside of the department.

All kinds of specialization might require approval at multiple levels within the institution. The survey asked specifically about approval by the department, college, university, board or trustees, and regents. The results are shown in Figure 5. Approval is required by the department for all types of specializations at all departments. Above the department level, about 20% fewer institutions require approval for concentrations than for minors and other specializations. Although fewer institutions require approval for concentrations, Figure 2 shows far more minors (22) and others (17) were added compared to concentrations (5). This data appears to indicate that concentrations were not added simply due to bureaucratic ease. Approval requirements are essentially the same (given the number of respondents) for minors and other specializations at all levels of approval. Approval is required less moving higher into the university structure, but approval by board or trustees is still required at 30% of institutions for minors and other specializations. It might seem odd that we asked about trustees and regents separately, but 15% of the institutions with minors replied that they required approval by both groups.

Specializations may or may not appear on the student's transcript. All institutions reported that minors appear on the transcript. Concentrations appear on the transcript at 54% of the institutions, and other specializations are transcripted at only 41% of the institutions.

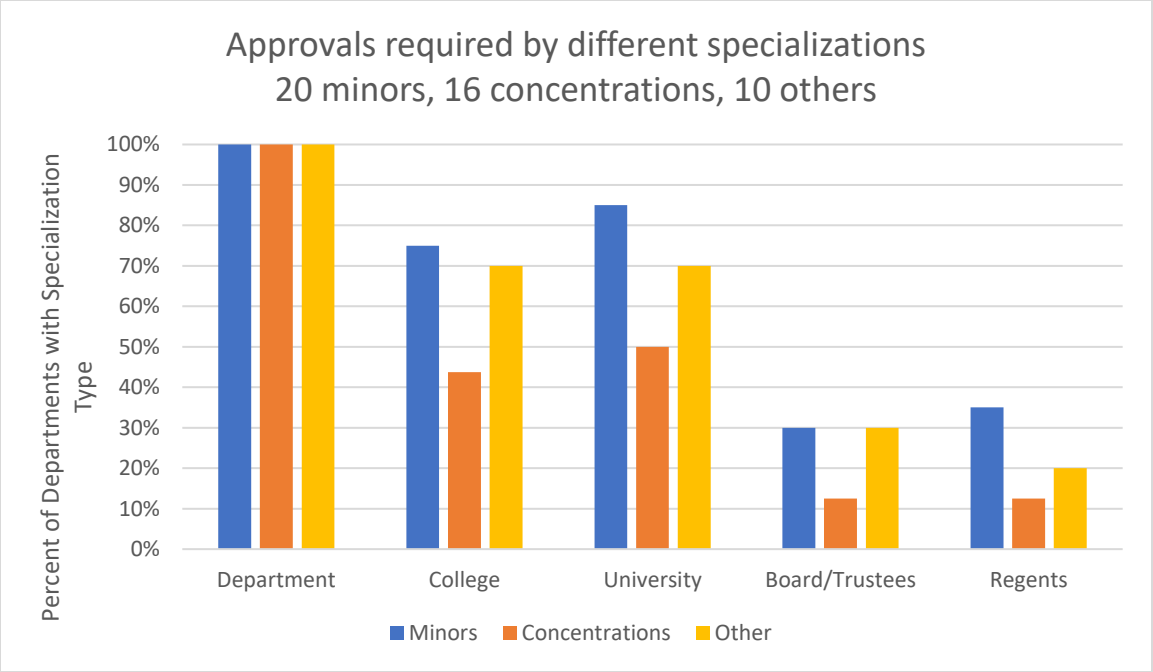

Figure 5. Approvals required for different types of specializations.

We asked if required and elective courses within the major may be double-counted in a specialization, as allowing courses to be double-counted will make the specializations easier to earn. The options for these questions were yes without limits, yes with limits, and no. Institutions are evenly divided between the options for double-counting *required* courses: 33% yes without limits, 36% yes with limits, and 30% no. For those departments that have them, the limit on double-counting *required* courses is a median of 6 credit hours, with a higher average of 7.9 credit hours. *Elective* courses are much more likely than required courses to be eligible for double-counting in a specialization: 72% yes without limits, 25% yes with limits, and 3% no. All three reported limits for double-counting elective courses were 6 credit hours. There were some additional limits on double-counting courses reported: 12 total credit hours can be double-counted between required and elective course at one institution and no course can be double-counted between two minors and/or certificates at another institution.

Allowing internships and/or undergraduate research to count toward specializations may also make the specializations easier to earn. Institutions were nearly evenly split in allowing these types of courses: 48% allow them to count and 52% do not count them towards specializations. Four institutions specifically mentioned that undergraduate research is allowed but internships are not allowed or are very rarely used for specialization credit. The research must be related to the specialization topic and unpaid. A proposal and final report approved by the department is required at one institution. Six other departments reported restrictions on the number of hours of research or internship – typically 1 – 2 semesters or 3 – 6 hours.

Our last questions were about how many students complete specializations, either inside or outside the department. Table 2 presents the approximate number of specializations completed per BS chemical engineering graduate. The averages and medians for all specializations are less

than one per student, with the highest being about half of the students complete a minor. Students complete more minors than other specializations, and students complete more other specializations than concentrations. Minors are always transcripted and may therefore be valued more by students and completed more often by students. Other specializations require fewer hours than concentrations do, which may be why more other specializations are completed per student than concentrations.

Table 2. Approximate average number of specializations completed per BS graduate in the department.

Type	Replies	Average	Median	Range
Minor	20	0.66	0.45	0.2 – 2.5
Concentrations	7	0.41	0.25	0 - 1
Other specialization	8	0.51	0.35	0 - 1

Table 3 presents approximately how many students per year complete the specializations run by the responding departments. These students may be majoring in chemical engineering or in other disciplines, and the institutions are many different sizes, so comparing across departments is challenging. The averages are about the same for minors and other specializations, 19 or 20 students per year, but 28 students per year complete concentrations offered by the departments. The median values are all lower, but the median for minors is much lower at 13 students per year.

Table 3. Approximate average number of students of any major completing specializations run by the department.

Type	Replies	Average	Median	Range
Minor	11	20	13	2 – 80
Concentrations	8	28	23	4 – 75
Other specialization	6	19	18	4 – 40

Conclusions:

81% (35 of 43) departments reported offering one or more specializations. On average, minors required a minimum of 16.3 credits (mode 15) and concentrations 12.4 credits (mode 12), and other specializations had a mode of 9. This clear separation in credit requirements may explain why some departments offer multiple types of specializations. Specializations were grouped into categories: bio-type, energy, materials, process-type, sustainability, and other. Bio-type specializations were the most common. Significantly more specializations have been added over the last 10 years than removed (44 to 12). Bio-type led the way in additions (13) while materials (5) led in removals. Similar to broader trends in academia, data science/analytics specializations are starting to appear in chemical engineering departments. Significant pre-medicine and pre-law specializations in chemical engineering departments appear to show the desire of these departments to attract these students to their department with a clearly specified pathway toward subsequent goals.

Approval of specializations is consistent with minors and others consistently requiring more approval above the department level than concentrations. Double counting of both required major courses (69% without limits or with some limits) and elective courses (97% without limits or with some limits) was generally allowed. When limits were included, they were generally 6 credits. The typical student completes less than one specialization with the highest average being a minor at about half.

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Appendix A: Survey Questions

Q1 Joe Holles (New Mexico State) and Laura Ford (Tulsa) were intrigued by the question Dan Shantz (Tulane) asked in Fall 2023 about minors. This survey expands upon that question, with the results to be disseminated via ASEE and/or *Chemical Engineering Education*. These questions do not qualify as human subjects research.

Q2 Name of your institution _____

Q3 Name of your department _____

Q4 Names of undergraduate degrees offered in the department _____

Q5 Does your department offer any specializations (please select all that apply)

- ☐ Minors
- ☐ Concentrations
- ☐ Other specializations (please name the type) _____
- ☐ None of the above

Q6 How many credits are required for each of the following? Give a range if necessary.

- Minors _____
- Concentrations _____
- Other specializations _____

Q7 What levels of approval are required for each of the following?

	Department	College	University	Board/Trustees	Regents
Minors	☐	☐	☐	☐	☐
Concentrations	☐	☐	☐	☐	☐
Other specializations	☐	☐	☐	☐	☐

Q8 Do these appear on transcripts?

	Yes	No
Minors	○	○
Concentrations	○	○
Other specializations	○	○

Display This Question:

If Does your department offer any specializations (please select all that apply) != None of the above

Q9 Please list the names of the following offered in your department

- Minors _____
- Concentrations _____
- Other specializations _____

Display This Question:

If Does your department offer any specializations (please select all that apply) != None of the above

Q10 Please list any new specializations in your department that have been added in the past 10 years

- Minors _____
- Concentrations _____
- Other specializations _____

Q11 Please list any specializations that have been removed from your department in the past 10 years

- Minors _____
- Concentrations _____
- Other specializations _____

Display This Question:

If Does your department offer any specializations (please select all that apply) != None of the above

Q12 Are students allowed to double-count any **required** courses from your major as part of a specialization?

- Yes, without limits
- Yes, with limits (state limit) _____
- No

Display This Question:

If Does your department offer any specializations (please select all that apply) != None of the above

Q13 Are students allowed to double-count any **elective** courses from your major as part of a specialization?

- Yes, without limits
- Yes, with limits (state limit) _____
- No

Q14 Please list any specializations offered outside of your department that students commonly receive and any special circumstances (e.g., students in ChE automatically take enough credits that they also earn a chemistry minor). _____

Q15 Please list any restrictions on specializations, such as a university rule that engineering students cannot earn minors _____

Q16 What is the approximate average number of specializations completed per BS graduate in your department, if you have that information?

- Minors/graduate _____

- Concentrations/graduate _____
- Other specializations/graduate _____

Display This Question:

If Does your department offer any specializations (please select all that apply) != None of the above

Q17 Approximately how many students per year complete the specializations run by your department? These students can be from any major.

- Minors/year _____
- Concentrations/year _____
- Other specializations/year _____

Display This Question:

If Does your department offer any specializations (please select all that apply) != None of the above

Q18 Does your institution allow internship and/or undergraduate research to count towards a specialization? If so, please state any restrictions.

- Yes (state any restrictions) _____
- No

Q19 How many open engineering/technical/chemical engineering credits are in your BS program that students may use to count toward a specialization? _____

Q20 Please enter your email address if you would like the compiled results sent to you.

_____

Appendix B: Respondents

Auburn University
Bucknell University
Clemson University
Cleveland State University
FAMU-FSU College of Engineering
Florida Institute of Technology
Georgia Institute of Technology
Lafayette College
LSU
New Jersey Institute of Technology
New Mexico State University
New York University
North Carolina State University
Northeastern
Ohio University
Oregon State University
Princeton University
SUNY ESF
The Cooper Union
Tufts University
Tulane University
UMBC
University at Buffalo (SUNY)
University of Alabama
University of California Davis
University of Colorado Boulder
University of Dayton
University of Delaware
University of Florida
University of Kansas
University of Kentucky
University of Minnesota Duluth
University of North Dakota
University of Notre Dame
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