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Curriculum and Teaching Load in Top-Ranked U.S. Chemical Engineering Departments

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Intro:

Chemical Engineering department's curriculums are continuously changing, and it's important to quantify the state of teaching today, and emerging future trends. Such data can inform many decisions on the department and college level, from what is considered "core" chemical engineering content to the workload expected of engineering faculty.

Surveys, such as those from the "How we Teach" articles from members of the Chemical Engineering Division of ASEE, are excellent resources for quantifying chemical engineering pedagogy. The "How We Teach" surveys focus on a particular core chemical engineering course each year and have recently covered topics of Capstone [1], Material and Energy Balances [2], Kinetics and Reactions [3], Intro Classes [4], Thermodynamics [5], Unit Operation Labs [6], Process Control [7], and Transport [8] individually. However, fundamental limitations are present with any survey, such as non-response bias, and misrecollection.

This work serves to complement department surveys using three sources of publicly available data: 1. the ground truth of published course schedules; 2. Faculty numbers and position from staff pages on department websites; and 3. Each program's recommended 4-year BS program, BS/MS program, and masters program. Data was collected from the 2022-23 school year, through all three semesters or all four quarters of the academic year. In total, 35 different chemical engineering programs were assessed. Of these programs, 29 are the top ranked national chemical engineering programs according to US News & World Report [9]; 6 additional state schools from the PAC-12 represent the remainder. Using the assembled database, this work examines departments' 4-year undergraduate curriculums, master programs, and the teaching load and composition of faculty members within the department. While there are limitations in relying on some of these data sources, our work may serve to provide a snapshot of chemical engineering curricula in the United States, to aid departments in comparing how their curriculum and department line-up with current and emerging trends.

Methodology:

For collecting bachelor of science (or engineering) curriculum data, schools' public 4-year plans were used to find the number of credits for each class and the year in that plan at which they are recommended to be taken. The credits for each curriculum were scaled such that there were 128 total credits for each program, by multiplying each class credit with the ratio (128 / total number of credits in 4-year curriculum), making an average class roughly 3-4 credits. 128 credits was chosen as the normalizer due to it being the average number of credits in a semesterly 4-year program. This scaling was done to group quarter and semester systems together, and reconcile various credit systems. The year the class is taken was represented from a scale of 1-4, with 1 representing the first year, and 4 representing senior year. So, if a particular class is taken as a sophomore in half of the departments and a junior in the other half, it would be represented as a 2.5.

Data for master programs were taken from institution websites and public graduate student handbooks. If a school had multiple programs, such as thesis and coursework, only the thesis program was considered.

Faculty information was taken from department web pages. For classifying professor positions, faculty ranks were classified as associate, assistant, or full, and either tenure-track or lecturer (e.g. professors of practice, and teaching professors).

Teaching data was taken from public online course catalogs; only chemical engineering classes were considered. If a class was taught in another department by a chemical engineering professor, it was not included in our analysis.

For teaching load calculations, the majority of course credit hours were simply attributable to a single faculty member. However, a minority of courses necessitated an alternative counting. If a class was taught by multiple different professors, those faculty were each given credit for teaching the class. This choice was made because it is unclear, with publicly available data, how teaching load is divided between faculty of co-taught courses. Further, a course taught by two faculty does not reliably indicate that the sum of their efforts would not go beyond the effort of a single faculty teaching the same lecture course. This choice could conceivably add a small but indeterminable overestimation of faculty teaching loads.

If a professor taught multiple sections of the same class, the faculty was attributed credit for the class multiple times. In contrast, faculty who taught multiple laboratory sections were only given credit for one section. It was found that some departments offer many laboratory sections attributable to multiple faculty members, where it's unclear how workload is divided. So, if each lab teaching professor was given credit for each lab course they would have a significantly higher credit count than their lecturing peers. These choices could respectively overestimate and underestimate teaching load calculations, but due to the low percentage of courses that meet this scenario, the impact should be minimal.

Limitations:

Data collected from public sources has the possibility of being archaic and unrepresentative of reality. This is unlikely to be the case with the 4-year plan data and teaching loads course catalog data, due to the large amount of students interacting with that information making mistakes more costly. However, mistakes may be prevalent within graduate student handbooks due to the large amount of information and fewer students, and faculty information on department web pages due to the low urgency of updating recently promoted faculties titles.

Furthermore, data for this study was collected manually from a single participant. According to a study examining the error rate of manually entering data [10], participants made 12.03 mistakes out of 1260 entries meaning there's roughly a 1% error rate in manually inputting data. These mistakes wouldn't be large such as inputting 11 instead of 1 due to the noticeable effect on the results, however, it's possible that ~1% of entries were placed in the wrong cell or have an incorrect value.

Another limitation with collecting from public data is the collector's understanding is surface level compared to collecting data in a survey, where whoever's filling out the form has a deeper understanding of the content. For example, when finding a department's 4-year bachelor's curriculum a course may be titled "Intro to Chemical Engineering", but the content taught matches more closely to "Material and Energy Balance". This work would have labeled that class as "Intro to Chemical Engineering", whereas a department filling out a survey could have recognized that as their "Material and Energy Balance" class.

Results:

Bachelor of Science Curriculum

Figure 1 is a summary of the 4-year plans for all departments. Common STEM classes such as general chemistry, physics, and calculus are omitted. Courses that include defining chemical engineering content that are not at the level of 100% inclusion in chemical engineering curriculum are most likely obscured in an unusual course name. For instance, Chemical Reaction Engineering is only at 94% but it is most likely that all of the top chemical engineering programs offer training in core chemical reaction engineering concepts, in courses named "Kinetics" or in their transport courses. The data in Figure 1 should be considered lower bounds.

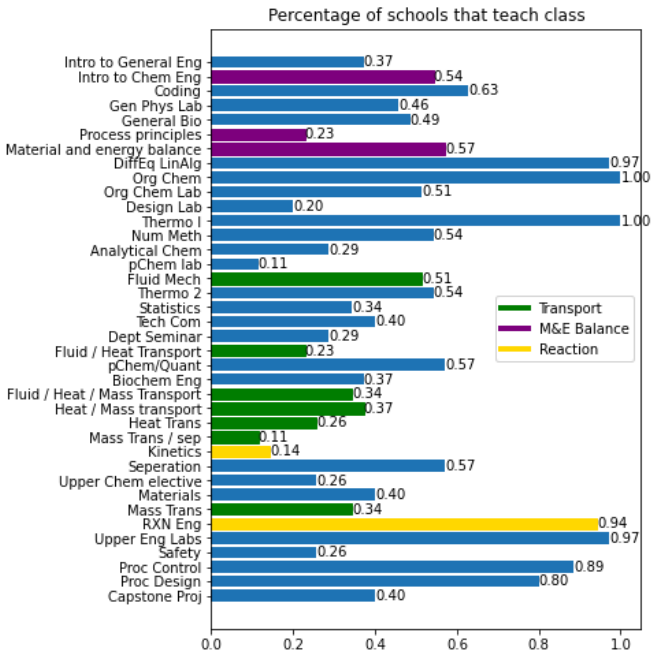

Fig. 1a

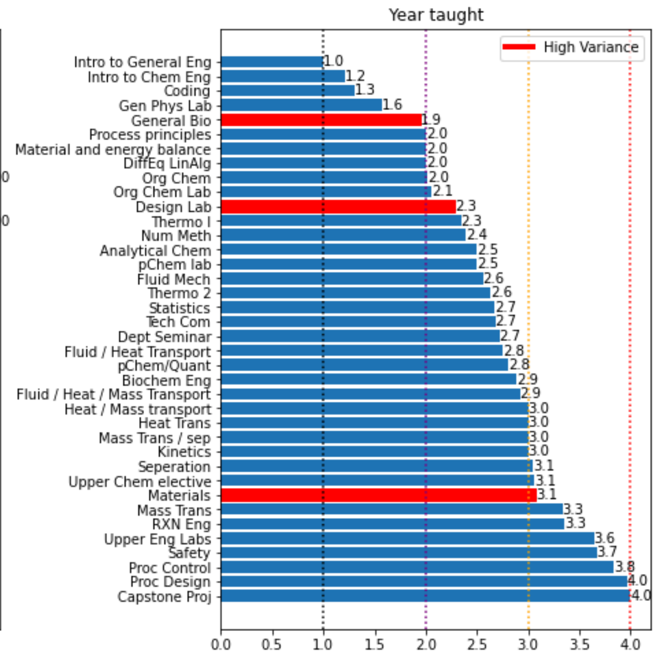

Fig. 1b

Figure 1 Department Curriculum: a) Percent of courses that require each listed course. Color groups indicate courses that likely include similar content under different labels. b) Average year in which this course is taken by students. The red bars indicate courses that are taught with variance greater than 2 years in a 4-year program.

For interpreting Figure 1b, it can be assumed that there is only variance between two years for blue bars, meaning every program has its respective classes set to take place within a year of each other. So, process principles value of 2 means it's taught sophomore year in 100% of the departments surveyed, not 50% first year and 50% junior year. However, if a class is highlighted red this assumption isn't true. Such classes are general biology with a composition of 35% first year, 35% second year, and 29% third year. Design lab with a composition of 57% first year, and 43% fourth year, indicating a substantive split between departments with introductory design experiences and departments that keep these lab experiences at the end of their curriculum. Finally, Materials has a composition of 21% second year, 50% third year, and 29% fourth year.

Figure 2 shows how catalog data compares to the survey data from various "How We Teach" ASEE articles from the Chemical Engineering Division leaders. In general, there is reasonable agreement, with some notable deviations.

For instance, only 57% of schools have a specific material and energy balance class listed in their online catalog data, but 99% are indicated in survey data. As mentioned above, that doesn't mean only 57% of schools truly teach that content. In reality, the other 42% most likely teach the content in either process principles, intro to chemical engineering, or within a different class name. Note, for example, that we show 54% of departments teach an Introduction to Chemical Engineering course, compared to 35% in survey data. It is likely the material and energy balances are taught in their introductory course.

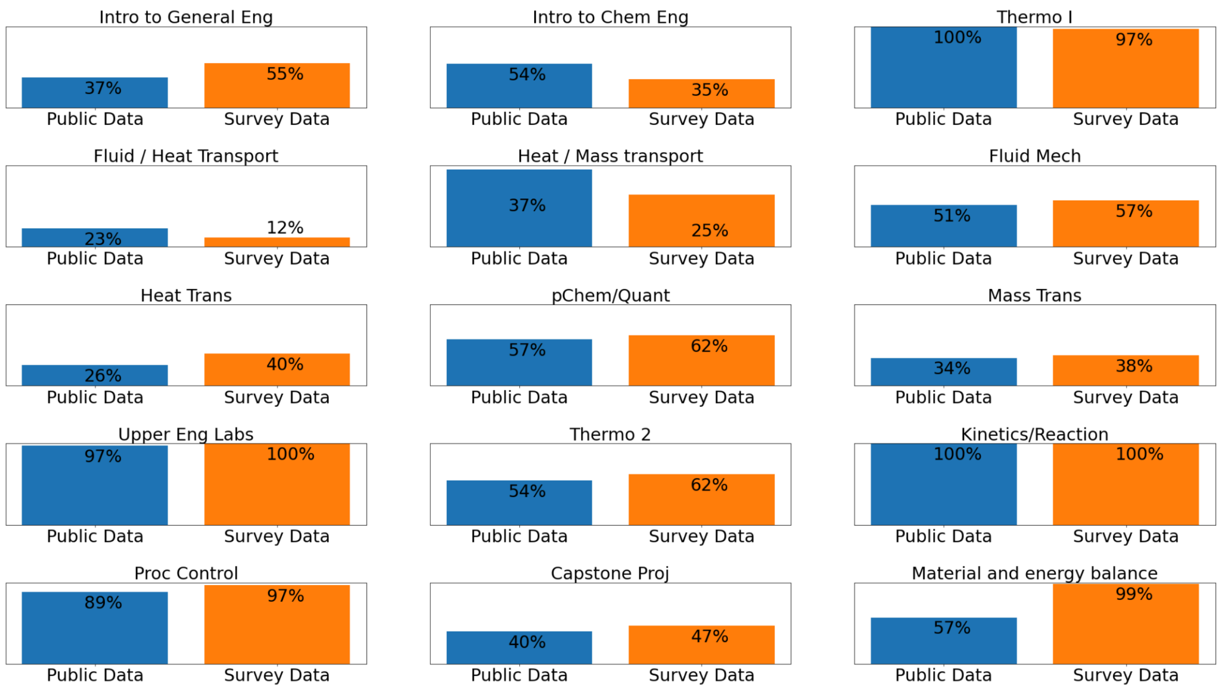

Figure 2. Catalog data compared with "How we Teach" surveys. Y-axes are scaled from 0 to 100.

Disagreements could also be due to the sampling difference in the "How We Teach" surveys, which examines a wider variety of departments and typically takes data from a single department representative. However, for the transport courses, a significant difference may also exist due to the survey data not being able to classify courses such as "Transport I", for example, so 19.35% of all entries were in the "other" category [8]. With the public data, similarly titled courses were put into a category by looking at the syllabus, when available, to see what's taught.

Figure 3. examines the distribution of lab credits and elective credits. The lab credits include general chemistry, organic chemistry, physical chemistry, physics, and upper engineering labs

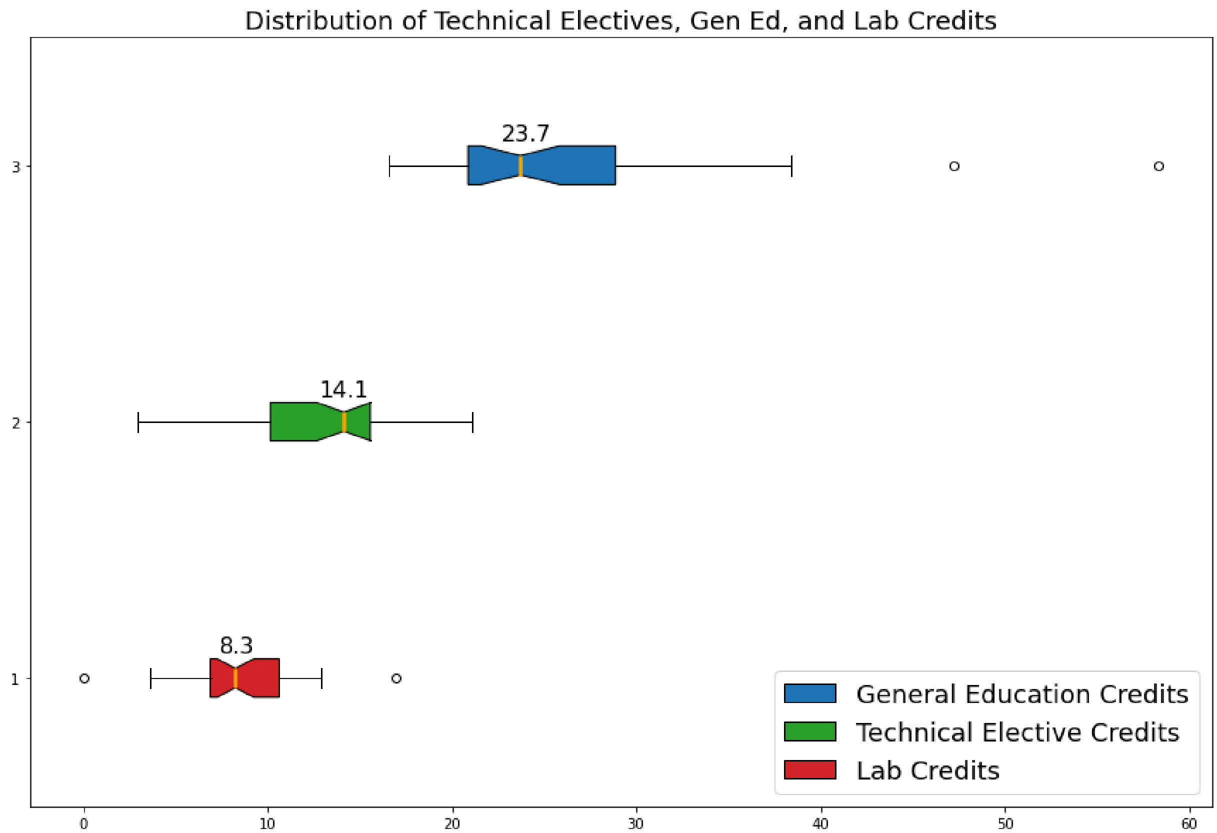

Figure 3. Distribution of credit hours for labs and electives. Credit hours are normalized to 128 total hours.

The two outliers for the general education credits both have multiple types of credits. The first is the standard social study requirements, while the other is an unrestricted elective. So, the large amount of general education credits required reflects more freedom in the curriculum rather than an emphasis on social studies.

MS/BS program:

Out of the 35 schools examined in this study, 30 (86%) had a chemical engineering master's degree program. All statistics from this section will be in reference to those 30 schools.

50% of schools with a MS program offer a MS/BS program. However, out of those 15 schools, there are varying levels of credit reduction offered for BS/MS plans. Defining credit reduction as credits that count towards both a bachelor's and master's degree, and with the average class being 3 credits: 2 schools offer 12 credit reduction, 3 schools offer 9 credit reduction, 6 schools offer 6 credit reduction, and 4 schools don't offer credit reduction but give other benefits. Examples of those benefits may be allowing students to take master's degree classes their junior/senior year that don't count towards their bachelor's degree, or not requiring a thesis.

Looking more at the contents of the master's degrees, 80% of schools offered a thesis program while 70% of schools offered both a thesis and a different program, such as coursework or professional development.

Figure 4 shows the distribution of courses in the MS thesis curriculum that students with a chemical engineering BS degree have to take. This data is only for students with a BS in chemical engineering, students from other majors often need to take retread courses to learn the fundamentals of chemical engineering before taking those classes. For a semesterly program, the median number of "core" classes (any class excluding thesis research, seminars, and electives) is 3. The median number of elective classes is 4. The median amount of research required is equivalent to 3 classes. Therefore, the most common thesis curriculum for a semesterly program would be 4 elective classes, 3 core classes, and 3 classes worth of research, with required graduate seminars.

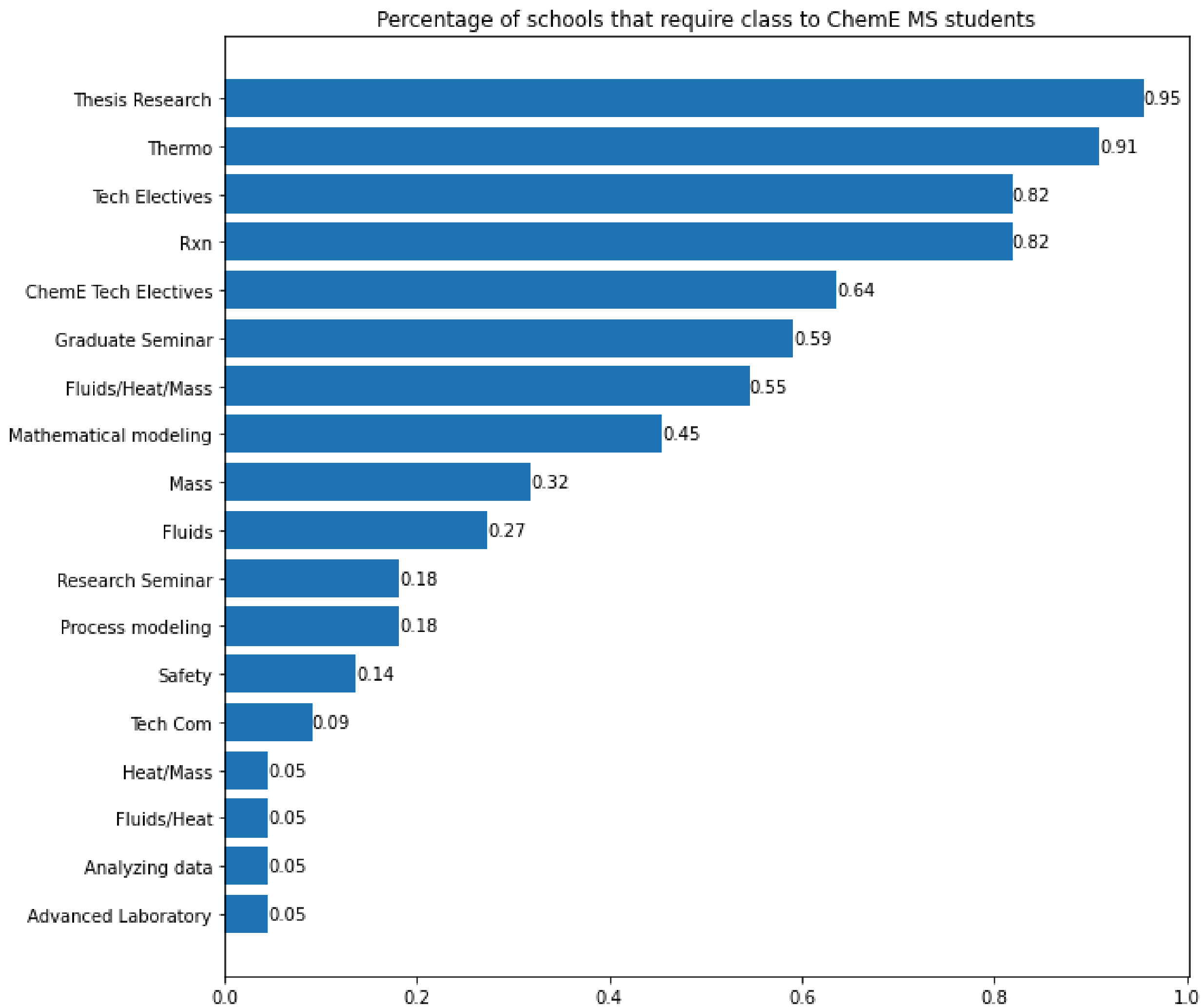

Figure 4. MS Degree Requirements: Percentage of schools that require certain courses in their thesis curriculum for students with a chemical engineering BS degree.

For a quarterly program, the most common curriculum is 4 core classes, 3 elective classes, and 5 classes worth of research, with required graduate seminars. Interestingly, this is exactly like the semesterly programs, except there are two more "classes" of research.

A minority of departments (13%) require MS students to have taken all the major chemical engineering classes before being admitted, meaning they offer no retread courses. 60% of schools will offer retread courses depending on the students' academic history. Departments that have a set retread program outlined in their graduate student handbook are 27% of the sample.

Looking at the 27% of schools with set retread plans, there is a large variety in how programs treat retread programs. A typical program requires 3-4 classes with the most common composition being a thermodynamics class, a reactions class, and 1-2 transport classes. However, there are some unique ways programs approach retread courses. One of them is offering an "Essentials of Chemical Engineering" course, which covers topics such as thermodynamics, transport, and reactions throughout two classes. Two of the eight programs that offer retread classes use this method. Another approach is offering a comprehensive exam that, if a student passes, allows them to bypass the corresponding prerequisite undergraduate course.

Teaching Load:

Figure 6 shows a box plot of the number of classes and credits that each professor type teaches in a school year. These data are collected from the publicly available course registrar of each school, which was available in 28 schools. It should be noted that this figure does not represent a distribution of every individual professor's teaching load in the survey. Instead, the box plot represents the distribution of average teaching loads across institutions.

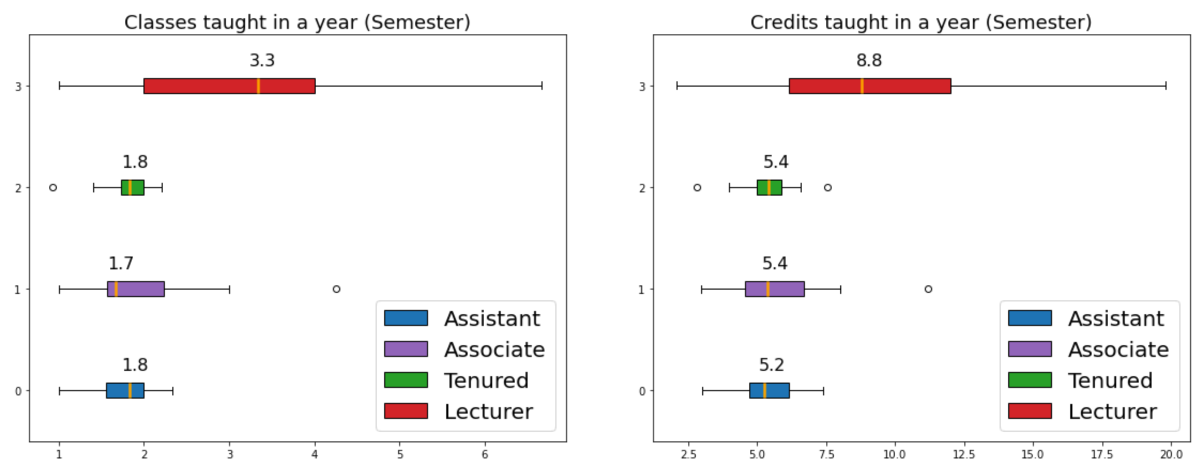

Fig. 6a **Fig. 6b**

Figure 6. Semesterly Teaching Load: a) The number of classes taught in a semesterly school year for each professor type. b) Number of credits taught in a semesterly school year for each professor type scaled at 128 credits.

There is a noticeable difference in ranges between professor types. Tenured has a very low interquartile range, most likely because there are more tenured professors, causing outliers to be less significant in calculating the average. Meanwhile, lecturers have a very high interquartile range. This shows that schools have different teaching expectations from lecturers with the lower quartile expecting 2 classes taught a year and the upper quartile expecting 4 classes.

Figure 7 represents quarterly system schools. The number of credits is scaled to 180 credits following the same formula explained in the methodology, but replacing 128 with 180. With this, the average class is 4 credits. These graphs are similar to Figure 6, but with larger quartile ranges, possibly due to there being only 8 data points on each box plot (compared to 20 in Figure 6). Most departments are on the semester system.

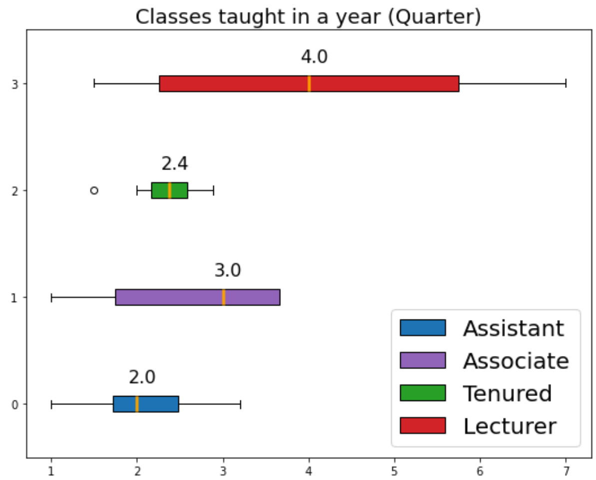

Fig. 7a

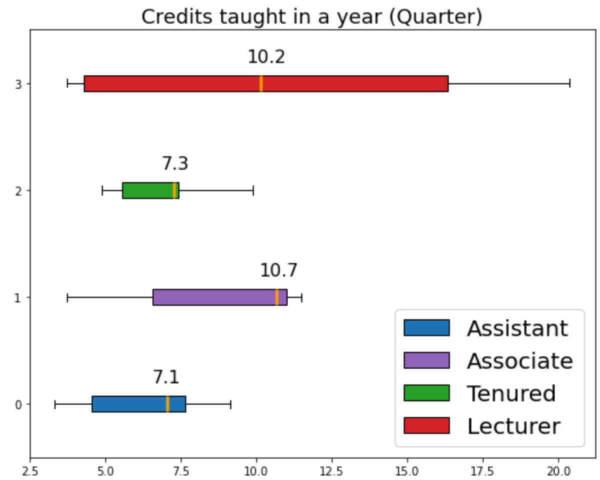

Fig. 7b

Figure 7. Quarterly Teaching Load: a) Number of credits taught by professor type at quarterly schools, scaled at 180 credits. b) Number of classes taught by each professor type at quarterly school

On average, tenure-track chemical engineering assistant professors teach slightly less than one course per semester or quarter. This lower load is likely due to departments giving new faculty the option to opt out of teaching one semester or quarter in their first year, to accelerate their research programs. In the semester system, full and associate professors teach about the same amount, whereas, in the quarter system, associate professors teach slightly more. Above assistant professors, chemical engineering faculty generally teach one course per semester or quarter. Lecturing faculty generally teach twice as much as their tenure-track counterparts in the semesterly system, and 1.5 times as much in the quarterly system.

Figure 8 shows how many professors of each type there are throughout all 35 chemical engineering programs included in this survey. Lecturers are the least common professor type with 14% of schools not having any lecturer faculty, and tenured is the most common type.

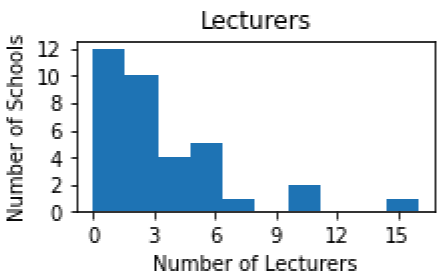

Fig 8a

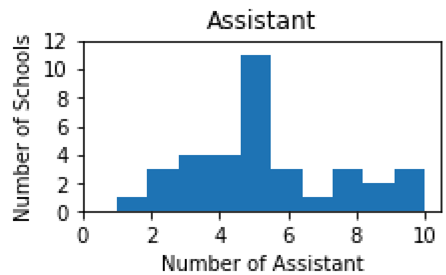

Fig 8b

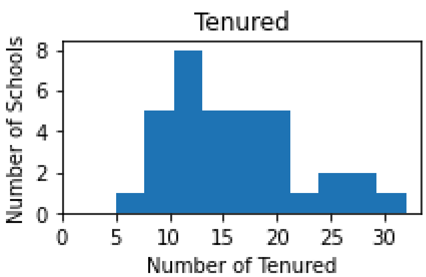

Fig 8c

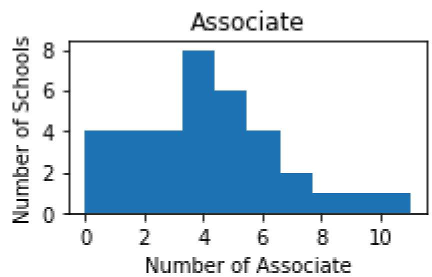

Fig 8d

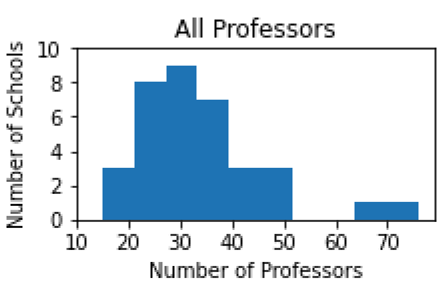

Fig 8e

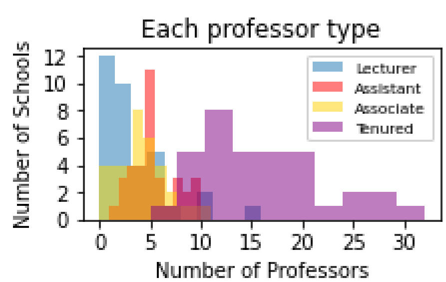

Fig 8f

Figure 9 shows the same data as Figure 8f with a different method of visualization.

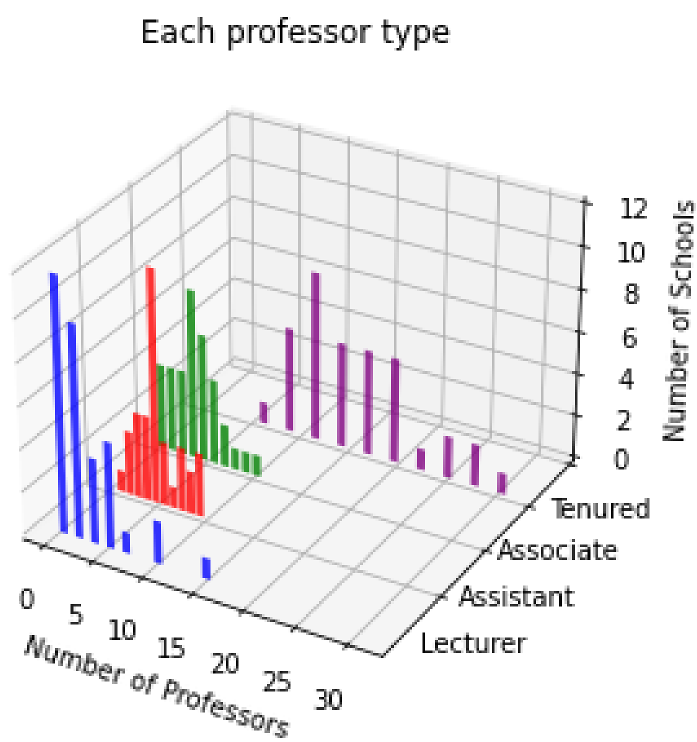

Fig 9. Number of Professors for each title.

Conclusion

Through public data, a snapshot of curriculum, department makeup, and teaching loads was recorded from top-ranked chemical engineering departments in the United States. 35 chemical engineering programs' curricula were examined ranging from undergrad to grad school. Looking at undergraduate 4-year programs: the percentage of courses required and the year they're taught was found, and this was compared with previous survey data. The number of lab, general education, and technical elective credits required were also looked at. In general good agreement was found with "How We Teach" survey methods.

For master degree programs: the number of BS/MS programs was looked at, and how those programs functioned. In the thesis curriculum, the percentage of courses required and the average curriculum was looked at. How programs teach non-chemical engineering majors were also examined.

Regarding programs' teaching load: the average number of credits and classes taught by different types of professors was analyzed. This was done for both semester and quarter system schools. Finally, the number of each type of professor employed at different schools was examined. In general chemical engineering faculty teach one course per non-summer semester or quarter, with lecturing faculty teaching twice as many courses per year in semesterly systems, and 1.5 times as many courses in quarterly systems compared to tenure-track faculty.

This data may have several uses.

The authors offer no assurances that the curricula of departments ranked highly by US News and World Report should be considered to be curricula that result in exemplary learning outcomes. They are simply examples of chemical engineering curricula that correlate with departments that are highly regarded. As such, this data may be used with caution to supplement departments in their decisions regarding their curriculum. What should be included, or excluded? How does a department compare to the schools that students are being told are the top institutions? What are the emerging trends? For example, first-year design lab experiences for chemical engineering students were once rare, but we now find them in about half of our survey population. Furthermore, such data could be used to identify gaps in the top programs that could be used to distinguish a department.

This data may also be useful to department chairs in decisions around faculty composition. This work gives a picture of the ratios of faculty ranks for departments that are regarded as highly effective. Both department chairs and prospective faculty could also be aided in understanding what is a common teaching load in the faculty marketplace. For example and anecdotally, we have found that official college teaching load policies require far more credit hours than what faculty actually are teaching, in both conversations with colleagues and in the ground truth of their published course schedules shown in this data. This work can be used to better couple policy with the reality in the engineering colleges that produce the most regarded chemical engineering programs.

Citations

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