Main Course or Buffet? Degree of Student Specialization in Elective Choices

Julia Sonnenberg-Klein
School of Electrical & Computer Engineering
Georgia Institute of Technology
Atlanta, GA, USA
jsk@gatech.edu

Elliot Moore
School of Electrical & Computer Engineering
Georgia Institute of Technology
Atlanta, GA, USA
em80@gatech.edu

***Abstract*—Electrical Engineering and Computer Engineering are broad disciplines. If students are given a wide selection of electives within their majors, how do they navigate the curriculum? At one extreme, a student could choose electives from one or two areas, creating specialization in their program of study. Conversely, a student could evenly sample courses from across the discipline, providing a broad foundation in the field. This analysis examines in-major elective enrollments in two majors, Electrical Engineering and Computer Engineering, to determine the degree to which students constructed specialized or broad programs of study prior to a curriculum revision, with analysis at the student level (N = 2,013). Measures of specialization are based on course categorizations developed for a new threaded curriculum in which courses are assigned to threads (specializations), and students choose courses from two threads. The extent of specialization that occurred before the new curriculum was measured by students' enrollment in courses corresponding to each new thread, with examination of the number of credits in their largest and second largest threads, and credits earned that could apply to threads in each major. Results show nominal specialization, nominal differentiation between the two majors, no correlation between academic achievement and specialization, and no inequity by status as historically underserved minorities, gender, first-generation status, or transfer student status. The study is novel because it examines the degree to which students constructed specializations within or evenly sampled courses across a broad discipline. The approach will provide departments in broad disciplines a new way of understanding the educations they provide their students, from broad to specialized, and whether these educations align with departmental goals. A limitation of the study is that it does not differentiate between the two majors, it does not differentiate between students who double-majored in both Electrical Engineering and Computer Engineering, and withdrawals were treated as enrollments. Controlling for these factors, future studies will examine the complexity of the old and new curricular models to quantify losses and gains, with a focus on factors that block and delay student progress toward graduation.**

Keywords—Curriculum development, electrical engineering education, computer engineering education

I. Introduction

Designing curriculums for Electrical Engineering (EE) and Computer Engineering (CmpE) grows more complex as the disciplines become more intertwined in disparate areas. The interaction of EE and CmpE with multiple disciplines [1] calls for continued examination of what it means to provide an education for future EE and CmpE students. This provides a unique opportunity to rethink what an engineering curriculum should look like for current and future generations. The concept of training every EE and/or CmpE student in the exact same way must give way to providing more flexible paths for students to engage the curriculum based on their personal goals, and give a way to better align undergraduate education with the diverse skills now necessary to build a successful career.

As reported in a previous paper [2], the School of Electrical and Computer Engineering (ECE) at the Georgia Institute of Technology (Georgia Tech) undertook a curriculum revision process, with the intention of providing better clarity and focus to both students and industry partners by aligning areas of specialization (threads) to broad career interests. In the initial phase, the department examined how student enrollment aligned with 11 Technical Interest Areas built around faculty research areas within the school. In Fall 2021, the School implemented a threaded curriculum, modeled after the Bachelor of Science in Computer Science (CS) degree program in the College of Computing at Georgia Tech [3]. The new curriculum provides students with 5 unique EE threads, 3 unique CmpE threads, 3 shared EE/CmpE threads, and 3 threads that are accessible to both CmpE and CS students.

To understand the degree to which the new curriculum affects students, the department must first understand how students navigated the old curriculum, providing a baseline for comparison. For this study, the new thread structure was used as a metric to determine the extent to which students under the old curriculum constructed coherent programs of study. The analysis examined four relationships: the degree to which enrollment in courses now associated with threads showed differentiation between the two majors; the degree to which students' programs of study aligned with the new threads; correlation between academic achievement and thread-like enrollment patterns; and equity in enrollment patterns.

II. Background

Coherency is a key theme of curriculum design. However, EE and CmpE involve a myriad of viable career paths that can be difficult to articulate (as with other engineering disciplines). While a student could choose electives one course at a time, degree programs should provide students with coherent structures and clear paths to their interests and potential careers.

Traditionally, engineering degrees have relied on the concept of a core set of classes followed by a variety of elective courses from which students can choose. However, it can be difficult for students to see the connection between a course or series of courses and potential careers or areas of interest. While academic advising can assist, the complexity of elective course selection has motivated efforts at other universities to provide automated student guidance, with machine learning generating course recommendations based on student profiles [4-6] as well as semantic analysis of similar courses [7].

In ECE at Georgia Tech, classes are internally organized by Technical Interest Area which align with faculty research areas. However, the courses within each Technical Interest Area can relate to multiple Technical Interest Areas and career paths. A well-informed student could construct a coherent path by choosing electives from multiple Technical Interest Areas. Unfortunately, the volume of courses scattered across Technical Interest Areas can make it difficult for students to identify courses related to their interests, and unpredictability in elective offerings make it difficult to map elective choices out in advance. As a result, in curriculum revision discussions, students reported that they were unable to navigate coherent sets of electives in specific areas of interest.

At the heart of challenges in student elective selection is the complexity of undergraduate curricula. It is therefore important to utilize institutional data and curricular analysis to inform administrative efforts to simplify and inform the process for students to identify coherent paths through the undergraduate curriculum to their career paths.

An overview of curricular analysis techniques in [8] determined that the two primary factors affecting the structural complexity of curriculum were related to *delay* and *blocking* factors. Delay factors related to courses in long course sequences that required multiple semesters to complete. Blocking factors related to courses that were prerequisites for several other courses where failure to pass it would delay graduation. Work in [9, 10] used delay and blocking factors to quantify the concept of *course cruciality* that enabled the ranking of courses based on their impact on student progress in the curriculum. The work in [9] closely relates conceptually to the work in this paper where the canonical (intended) degree path is compared to the actual path taken reflected by the students course choices. The results in [9] suggested that students did not follow the canonical path, instead taking lighter course loads each term and more extraneous courses that led to increased graduation times.

After several years of collecting feedback from faculty, students [2], and industry advisory board members, the School of Electrical and Computer Engineering adopted a new undergraduate curriculum centered around threads [3].

III. CURRICULUM STRUCTURE

In the new threaded curriculum, students completing bachelor's degrees choose two threads and complete approximately 12 credit hours in each. (For context, a minor at Georgia Tech is 15 hours.) Each thread is a collection of classes beyond a subset of core classes which differ for EE and CmpE students. In each set of thread courses, one or two courses are required, and up to two classes can be chosen from a list of classes relevant to the thread area.

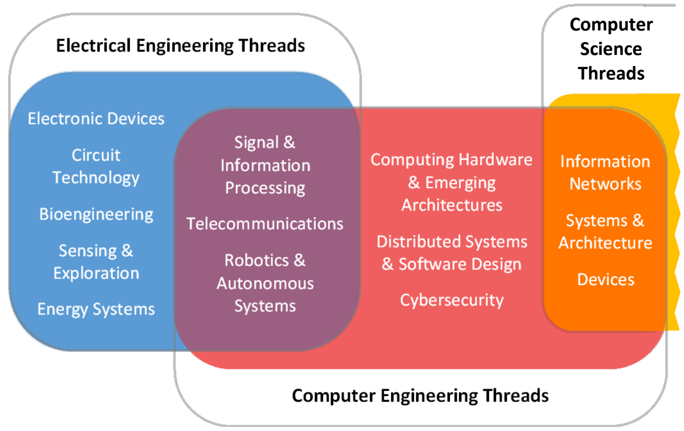

Fig 1. Electrical Engineering, Computer Engineering, and Computer Science threads.

The new curriculum reduced the number of junior-level courses required of all EE and CmpE students and organized within-major electives into coherent themes (threads). The curriculum offers 5 unique EE threads, 3 unique CmpE threads, 3 threads shared between EE and CmpE, and 3 threads that are accessible to both CmpE and CS students (Fig. 1). Completion of the BS degree requires selection of two threads for each major based on the following conditions:

- EE: **Any** EE **and/or** joint EE/CmpE threads (blue and purple in Fig. 1).
- CmpE: **At least one** CmpE-only thread (red in Fig. 1) **and** either a CmpE (red), a joint EE/CmpE (purple), or joint CmpE/CS (orange) thread.

In partnership with the College of Computing, students in CS and CmpE can participate in the three shared CS/CmpE threads (orange in Fig. 1), increasing CmpE student access to CS courses and vise versa. (This request had been loudly voiced over many years by students and faculty.)

As mentioned in the discussion of Technical Interest Areas, some courses apply to more than one area. Similarly, some courses can fulfill requirements in more than one thread, as illustrated in Fig. 2. This gives students the flexibility to switch between thread choices without hindering progress toward graduation.

Beyond courses that can count toward more than one thread in a single major, 30% of thread-eligible courses can count toward threads in both majors (Fig. 2). This is driven primarily by the shared EE and CmpE threads (purple in Fig. 1).

IV. METHODS

The goal of the analysis was to determine the degree to which students under the old curriculum constructed coherent programs of study, with the new threaded curriculum used as a measure of coherence in two areas. In the threaded curriculum, students select at least four courses (12 credit-hours), from courses approved for each of two threads. For this reason, 12

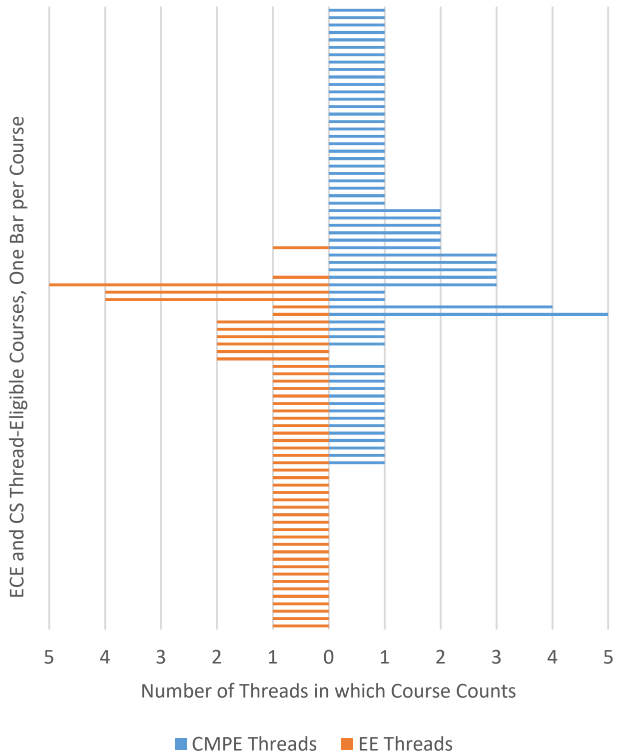

Fig. 2. Distribution of ECE and CS courses across Electrical Engineering and Computer Engineering threads.

credit-hours was used as a threshold for a student under the old curriculum having created coherence in their program of study. As shown in Fig. 2, some courses can be applied to two threads. Because the focus of the analysis was on degree of specialization, when the number of credits were tallied for a student in a given thread to see if the student earned 12 credits in the thread, it did not matter if the course also counted under another thread (as would be the case in determining thread-completion for graduation under the new curriculum).

Because degree requirements for the two majors under the old curriculum were similar, enrollment patterns were considered across both majors, instead of in a separate analysis for each major.

A. Data

Enrollment information was obtained from the campus office of Institutional Research and Planning for students who matriculated in Fall 2012 and later, and who graduated by Spring 2021. The dataset consisted of one row per instance of course enrollment with a student identifier, race/ethnicity, status as a historically underserved minority, gender, status as a transfer student, status as a first-generation college student, and course subject code and number.

A list of courses that count under each thread was compiled with one row per course per thread. Each row contained the course subject code and number (which could be mapped to the other list), the thread under which the course counted, and the number of credits the course is worth. When a course counted toward more than one thread, it appeared in the list multiple times, appearing once for each thread under which it could count.

B. Overview of Data Preparation and Calculations

The analysis involved multiple tables, tallies, and averaging. The values of interest were the number of thread-eligible credits students enrolled in under each major, and the number of credits in each thread. An overview of data preparation and calculation steps is below. Data preparation and calculations of credits by major and thread were done in excel.

1. Tables were generated:
   a. An enrollment table was generated that listed every ECE and CS course taken by every student in the sample, with one row per enrollment instance, and a student identifier in each row. The subject code and course number were used as course identifiers. Duplicates were removed.
   b. A tally table was generated with one row per student. This table included demographics and the student identifier.
   c. A threads table was generated listing every course offered under every thread, the thread under which the course counted, and the number of credit hours the course is worth. When a course counted under more than one thread, it was listed one time for each thread (i.e. multiple times). The subject code and course number were used as course identifiers.
2. In the tally table, which had one row for each student, two columns were added, with one for each major. For each student, the total number of thread-eligible credits was tallied for each major.
3. In the tally table, a column was added for each thread under each major. For each student, a total was computed for each thread.
4. Totals for joint EE/CmpE threads differed between majors, as described in the following section. In the tally table, a column was added for each pair of corresponding threads, and the credits for each pair were averaged.
5. In the tally table, two columns were added. The excel expression “largest” was used to determine the number of credits in each student’s largest and second largest thread. The averaged values for corresponding thread pairs were used instead of using two values for corresponding threads.

C. Details for Determining Largest Threads

As described in step 1a above, a tally table was created with one row per student, along with their demographics. A column was added for each major, and a total was tallied for each student under each (step 2). A column was also added for each thread under each major (step 3), and a total was tallied for each student for each thread. This yielded tallies for each student under each major, under each of eight threads in electrical engineering, and under each of nine threads in computer engineering

The two majors have three threads in common. However, credits in the corresponding threads count differently in the two majors. In one major a course is required in the core, and in the other major the course is considered a thread course. To account for this, an additional column was added for each set of corresponding threads, to average the credits earned. This averaged value was used when considering students' largest and second largest thread to avoid counting a shared thread as both the largest and second largest thread for a student.

D. Analysis

The analysis examined four relationships: 1) the degree to which enrollment in courses now associated with threads showed differentiation between the two majors; 2) coherence in students' programs of study, as measured by aligned with the new threads; 3) correlation between academic achievement and thread-like enrollment patterns; and 3) equity in thread-like enrollment patterns. Tallies and plots were done in excel. Analysis of variance and correlation were done in SPSS.

1) Differentiation between Majors

To determine the degree to which student enrollments differed between the two majors, a ratio was calculated for student enrollment in credits that could count toward threads in one major to their enrollment in credits that could count toward threads in the other major, with the smaller number as the numerator. The mean and standard deviation of the ratio were calculated. Enrollments were also visualized with a bubble chart, with credits that could count toward computer engineering threads along one axis, credits that could count toward electrical engineering threads along the other, and the size of the bubble representing the number of students with the same balance of credits between the two majors.

2) Coherence in Programs of Study

To determine if students' elective choices led to enrollment patterns resembling the new threaded curriculum, the number of credits in students' two largest threads were calculated. In this calculation, the average credits in corresponding threads were used. This kept the overlap between corresponding threads from showing an artificially large second thread that was equivalent to the first thread.

Because the threaded curriculum requires at least 12 credits from each of two threads, the number of students with or without at least 12 credits in one and two threads were tallied. The number of credits in students' two largest threads were also illustrated in a scatter plot, with 12-credits used as the scale on both axes.

3) Academic Achievement and Thread-Like Enrollment

To determine if thread-like enrollment patterns were associated with academic achievement, SPSS was used to examine correlation between final GPA and credits earned in students' largest thread, as well as correlation between GPA and the sum of credits in students' two largest threads. (Note that corresponding threads were averaged instead of being double-counted).

4) Equity and Coherence in Programs of Study

Finally, to determine if there was equity in the degree to which students were able to construct coherent programs of study, SPSS was used to examine analysis of variance in the number of credits in students' two largest threads by status as historically underserved or historically advantaged, by gender, by transfer-student status, and by first-generation student status. To maintain a simple analysis, interactions between traits were not included in the model.

V. Results

The initial data set consisted of 53,874 course enrollment instances. Enrollments in recitations and graduate level courses were removed. Five percent of the remaining enrollment instances were duplicates, cases in which a student repeated a course or withdrew and then later enrolled in the course. Duplicate instances were removed leaving 45,460 enrollment instances and 2,013 students.

Across the student group, ratios of credits that could count toward threads in one major to credits that could count toward threads in the other major were calculated, with the smaller number as the numerator. The average ratio was .67, with a standard deviation of .17. The balance between student credits in thread courses for the two majors is illustrated in Fig. 3.

As explained in the methods section, before determining students' largest and second largest threads, credits in corresponding threads were averaged. Across the two majors, 10% of students earned 12 or more credits in their two largest threads; 42% earned 12 or more credits in their largest thread and less than 12 credits in their second largest thread; and 48% of students earned less than 12 credits in any thread (Table 1, Fig. 4).

There was no correlation between final grade point average and the number of credits in students' largest thread ($r(2013) = .02$, $p = .31$) or the sum of credits in their two largest threads ($r(2013) = .02$, $p = .43$), as shown in Fig. 5.

Analysis of variance showed no difference in the number of credits in students' two largest threads by status as historically advantaged or underserved. Analysis showed differences but very small effect sizes for the other three demographic and

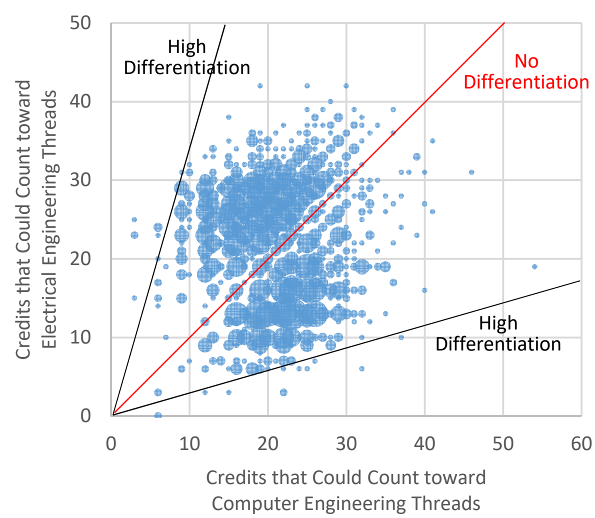

Fig. 3. Nominal differentation between majors.

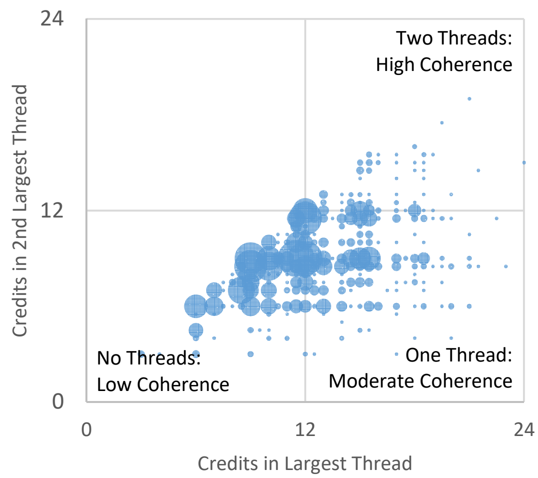

Fig 4. Coherence in program of study, measured by number of credits in two largest threads.

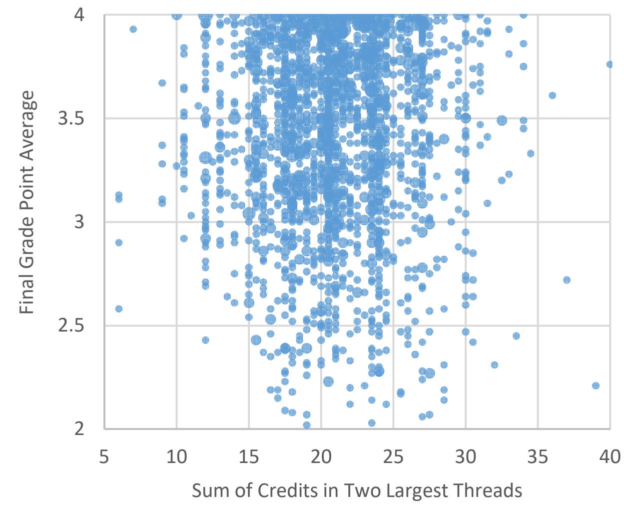

Fig. 5. Final grade point average by coherence of program of study.

background categories of gender ($F(1, 2007) = 13.56$, $p < .001$, $\eta_p^2 = 0.007$), status as a transfer student ($F(1, 2007) = 189.60$, $p = .002$, $\eta_p^2 = .005$), and status as a first-generation student ($F(2, 2007) = 5.48$, $p = .004$, $\eta_p^2 = .005$). For gender and transfer-student status, the group means were very similar (21.00 and 20.05 for male and female, 20.54 and 21.03 for transfers and non-transfers), agreeing with the small effect sizes. Post-hoc tests showed that differences by first-generation status were only significant between students with unknown status and students whose parents went to college. Means for the three groups were very close (20.46 for non-first-generation students, 21.21 for first-generation students, and 21.09 for students of unknown first-generation status), again agreeing with the small effect sizes.

VI. Discussion

A. Nominal Differentiation between Majors

In considering the ratio of thread-credits that could count in one major to thread-credits that could count in the other, a ratio of 1 would represent no differentiation between the two majors and would correspond with a diagonal line emanating from the origin, shown in red in Fig. 3. High differentiation between majors would be represented by a student taking a random selection of thread courses that counted in their major. Because 30% of courses count in both majors, this high-differentiation enrollment pattern would yield a ratio of 0.3. The clustering in Fig. 3 and the mean ratio of 0.67 indicates that in enrollment in thread-eligible courses, there was nominal differentiation between the two majors. If enrollment was more differentiated by major, the division along the diagonal in the figure would be more pronounced. If there were strong differentiation, there would be two clusters of data points, with one cluster along each "high differentiation" line. Instead, students enrolled in a wide breadth of classes across the two majors, falling almost evenly between high differentiation and no differentiation between the two majors.

TABLE I. Student Construction of Curricular Coherence

Enrollment Pattern	Credits	N	Percent
Low coherence	< 12 credits in any thread	957	48%
Moderate coherence	12 or more credits in one thread, but < 12 in others	851	42%
High coherence	12 or more credits in two threads	205	10%
Total		2,013	100%

B. Low Specialization

The new threaded curriculum is designed to give students a foundation in their major along with a coherent program of study in two areas (threads). To complete a thread, students take at least four courses (12 credit hours) in the thread. By this metric, very few students built coherent programs of study under the old curriculum. Under the old curriculum, nearly half of students (48%) earned less than 12 credits in courses aligned with any single thread, representing broad programs of study with low coherence. These students are represented in the lower-left quadrant of Fig. 4. Forty-two percent of students enrolled in one full thread, with less than 12 credit hours in a second thread, representing moderate coherence in their programs of study (lower-right quadrant). A small fraction of students (10%) enrolled in courses that would correspond with two full threads, representing coherent programs of study (upper-right quadrant). The new curriculum marks a substantial difference in the educations students received under the old curriculum, because new graduates will receive educations that are similar to only 10% of prior graduates.

C. Academic Achievement and Thread-like Enrollment

Investigators speculated that there would be a correlation between academic achievement and highly coherent programs of study, with high-achieving students more adeptly navigating the curriculum. However, there was no correlation between student grade point average and the number of credits they earned in their largest thread or the sum credits in their two largest threads. This means that students who created coherent programs of study were not more academically successful than students who constructed general programs of study.

D. Equity

While the results show low coherence in student programs of study, an encouraging finding was that there was not inequity in students' ability to construct coherent programs of study. Program coherence by student status as historically underserved or historically advantaged showed no statistical significance, and on all other demographics (gender, transfer student status and first-generation student status), effect sizes were negligible. This implies that students had equal access to resources that provided comparable levels of guidance. The sources of guidance may have differed by group, but the resulting program coherence did not differ.

E. Limitations

The study has a number of limitations. First, the analysis considered all instances of student enrollment, including instances in which students failed, withdrew from, and repeated courses. A complication of including instances in which students withdrew is that the inclusion may have artificially inflated credit totals in the analysis. This may have led to artificially high thread-credit counts, inflating the number of students who seemed to have constructed coherent programs of study.

Another limitation is that the analysis did not consider student major, nor whether students were double majoring. Had this information been included, the ratio between credits that could count toward each major would have been calculated separately for each major and for students double majoring in EE, CmpE or CS. This would have provided more information on enrollment patterns by major. Analysis of credits in students' largest and second largest threads would have also been done separately for double-majors. A portion of students with highly coherent programs of study (12 or more credits in each of two threads, upper right quadrant in Fig. 4) may have been double majors, but the information was not included in this analysis.

Another limitation is the scope of the analysis, which did not examine blocking and delay factors. Whether students dropped courses, repeated courses, or were double-majoring, Fig. 4 shows a wide distribution of total credits in thread-eligible courses, which requires further investigation.

VII. Conclusion

The new curriculum was introduced to better align students' programs of study with potential career paths. Development of the new curriculum was based on feedback collected over multiple years from students, faculty and industry partners. Feedback from all three sources indicated the programs of study lacked coherence, and the analysis agrees with those findings. Over a nine-year period under the old curriculum, only 10% of students constructed coherent programs of study, with coherence defined as 12 credit hours in each of two areas of specialization (threads) beyond a small core curriculum. It is unknown what portion of these students were double majoring in both EE and CmpE. Slightly more than half of students, 52%, achieved coherence in at least one thread, including the 10% of students with two threads. Forty-two percent of students constructed broad programs of study, taking courses in multiple areas, totaling less than 12 hours in any single area.

The enrollment patterns seen in the analysis are the result of multiple factors. The previous curriculum involved a larger and broader core, which required students to take classes now offered as thread courses under the new curriculum. As a result, students' programs of study under the old curriculum will be more general when compared to students under the new curriculum. To achieve coherent programs of study under the old curriculum, students would have had to plan carefully. However, the necessary planning would have been difficult because not all electives were offered in predictable rotations.

A notable pattern was the low level of differentiation between the two majors. This is seen in the ratios of credits each student could count under threads for one major or the other. Under the old curriculum, in-major elective choices were not prescriptive, and students made wide use of this freedom. Students evenly straddled their course enrollments between a strong focus in one major and even sampling across the two majors.

While this paper provides a baseline against which to compare enrollments for the new curriculum, additional dimensions are worthy of study, particularly blocking and delay factors for both the old and new curriculum and time to graduation. Future work will analyze and compare the complexity of the two models, to quantify the gains and potential losses in the adoption of the new curriculum.

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