Curricular Choice and Technical—Non-Technical Balance in Computer Science and Engineering Degree Programs

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***Abstract*—Many undergraduate engineering programs offer minimal course choice opportunities and constrain students in their ability to realize a broad and balanced education. This study delineates the course choice opportunities (i.e. free electives, technical electives, etc.) and balance of required technical and non-technical coursework in 62 computer science and computer engineering programs spanning 35 U.S. News & World Report top-ranked engineering colleges. Students in the studied computer science and engineering programs were afforded a median of 3% of their degree program as free electives and choices in 49% of total course selections. Across the same universities, other engineering disciplines provided even less choice (median 1% free electives and 39% total choice); in contrast, chemistry, math, and physics programs allotted a median of 17% free electives and choice in 67% of course selections. The computer science and engineering programs required a median of 74% technical coursework (engineering, math and natural science) and 23% non-technical coursework; students in these programs experience less curricular balance than their natural science and math peers. Flexible and balanced degree programs in computer science and engineering exist and may appeal to a broader sector of students, facilitate in-migration and on-time graduation, and reflect evolving societal needs.**

Keywords—course choice opportunity, curricular balance, humanities, multi-institution, social sciences, quantitative

I. Introduction

"Computing is a broad field that connects to and draws from many disciplines, including mathematics, electrical engineering, psychology, statistics, fine arts, linguistics, and physical and life sciences" [1]. The broad discipline of computing is reflected in multifarious computing degree program types, including computer science, computer engineering, and software engineering, and the diverse geographic homes of computing programs on university campuses. The extent to which computing degree program curricula reflect the curricular cultures of their campus homes—in engineering, business, or colleges of arts and sciences, for example—is nebulous. The modern-day role of computing as foundational and an "essential tool" for other disciplines, as well as the imperative to broaden and diversify participation in computing makes it "benefi[cial] [for] computer science departments to be 'outward facing,' building bridges to other departments and curriculum areas, encouraging students to engage in multidisciplinary work, and promoting programs that span computer science and other fields" [1].

In light of the imperative for educators to unremittingly reflect on and iterate their educational approaches and enterprises, curricular choice results from the delineation of cousin engineering programs warrant similar excavating of the curriculum of computing programs. Previous studies found that many engineering programs are autonomy un-supportive of students in terms of few course choice opportunities (i.e., free electives, technical electives, humanities electives), especially compared to their non-engineering peer programs [2] [3]. Across several dozen universities, non-engineering students were provided with the opportunity to choose a median of 74% of their total degree courses, compared to 40% for engineering students [3]. At these same universities, free electives (course choice opportunities with no restrictions) comprised a median of 24% of the non-engineering programs, compared to 3% for engineering [3]. This previous work included ABET Engineering Accreditation Commission (EAC)-accredited computing engineering programs, but only explored the median engineering degree requirements at each school; curricular choice for computing programs was not specifically reported. As with engineering, affording a computing student with opportunities to explore his or her individual learning interests as an undergraduate is appropriate preparation for the student to develop a "commitment to lifelong learning" [1].

Undergraduate students have an innate psychological need for autonomy, which can be satisfied through choice [4][5]. Further, most 18-24 year olds "significantly redefine their self-identity, a process which involves exploring many factors … including professional identity" [6]. Hence, results from the aforementioned study led to the hypothesis that the course choice opportunity disparity and low choice culture in engineering could be a poor match for students' developmental and psychological needs and therefore present a barrier to broader participation and success in undergraduate engineering education. Additionally, the constrained curricular model seems to present a logistical barrier for students interested in transferring in to engineering from other disciplines, thwarting

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on-time graduation and serving as a contributor to the low rate of in-migration to engineering [7]. Do these same curricular tendencies and vulnerabilities extend across computing programs?

The same question applies to the curricular balance opportunities provided to students in engineering and computing programs. Broad agreement exists that—in order to serve ethically, responsibly and effectively—it is important that engineers understand humanities and social sciences [8-24]. Engineering students are also generally constrained in their ability to realize a broad and balanced education [3]. In a study that delineated the curricular balance for more than 100 U.S. News & World Report [25] top-ranked chemical, civil, electrical, and mechanical engineering programs, the programs required a median of 78% technical coursework (engineering, math and natural science) versus 20% non-technical coursework (outside of engineering, math and natural science) [3]. The curricular balance for computer engineering and science degrees has not been previously examined in a comparable fashion.

Non-technical knowledge and skill sets are essential for computing professionals. In their 2013 curriculum guidelines for undergraduate degree programs in computer science, the Association for Computing Machinery (ACM) and IEEE Computer Society joint task force specified that "computer science curricula should be designed to provide students with the flexibility to work across many disciplines" [1]. This multidisciplinary curricular approach is also essential to addressing the "Social Issues and Professional Practice" component of the Computer Science Body of Knowledge; "while technical issues are central to the computing curriculum, … students must also be exposed to the larger societal context of computing to develop an understanding of the relevant social, ethical, legal and professional issues" [1].

Regardless of the identified tendencies in undergraduate engineering to implement highly constrained models (more than 75% technical curriculum), this curricular model is unnecessary from an accreditation standpoint. ABET EAC accreditation requires that a minimum of 2.5 years of a four-year curriculum (62.5%) be technical coursework, a substantial deviation from the median of 78% that was reported above from the study spanning more than 100 engineering programs. While ABET previously required a minimum of one-half-year (12.5%) of humanities and social sciences coursework, the current requirement provides for wider interpretation, specifying only "a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives" [26].

For ABET Computing Accreditation Commission (CAC) accreditation, fewer coursework requirements are specified than for EAC accreditation; CAC accreditation requires at least one year (25%) of "up-to-date coverage of fundamental and advanced topics in the computing discipline associated with the program … the program must include mathematics appropriate to the discipline beyond the pre-calculus level" [27]. As with EAC accreditation, the CAC general education requirements leave much room for interpretation and implementation, specifying only that "the curriculum must combine technical and professional requirements with general education requirements and electives to prepare students for a professional career and further study in the computing discipline associated with the program, and for functioning in modern society" [27].

Plainly, the EAC and CAC accreditation criteria each make it possible for computing programs to provide students with considerable opportunities for academic exploration and the pursuit of "non-technical" interests. This study extends the work of delineating curricular choice and balance by exploring the course choice opportunities and balance of required technical versus non-technical courses in the curriculum of computer science and computer engineering programs nationwide. Are students in the computing disciplines also experiencing a low choice curricular culture? Are these students afforded opportunities to pursue customized, broad, and/or balanced undergraduate academic experiences?

II. Research Questions

- How does course choice opportunity in computer science and computer engineering programs compare to that in other engineering and non-engineering science, technology, engineering and math (STEM) disciplines?
- How does the technical versus non-technical curricular balance of computer science and computer engineering programs compare to that of other engineering and non-engineering STEM disciplines?
- Does a difference exist in the course choice or curricular balance opportunities between computer engineering and software engineering programs versus computer science programs?

III. Methods

The computer science and computer engineering degree programs at the 2013 U.S. News & World Report's top 22 engineering colleges at doctoral-granting institutions and the top 24 engineering schools at non-doctoral granting institutions were delineated using the online university catalogs. Thirty-five of the universities offered computer science and/or computer engineering programs, including 20 doctoral-granting institutions and 15 non-doctoral granting institutions (see Table I for institutional characteristics).

A total of 62 accredited computer science and engineering degree programs spanned the 35 universities, including 24 computer engineering, 5 software engineering, 4 computer science and engineering, and 29 computer science programs. Twenty-seven of the 62 programs were EAC-accredited, 14 were CAC-accredited, four were both EAC- and CAC-accredited, and 17 of the programs were not accredited. Of the 29 computer science programs, four were non-accredited bachelor's of arts programs; the other 58 programs in the study were bachelor's of science programs. Seven of the studied computer science programs were offered outside of engineering colleges.

TABLE I. INSTITUTION DATA (35) FOR TOP-RANKED COMPUTER SCIENCE AND ENGINEERING PROGRAMS

Institution Type	Institution Classification [a]	Total Undergraduate Enrollment Size
Public (13) Private (22)	Bachelor's (3) Master's [b] (13) Doctoral [c] (19)	Small: <5000 (12) Medium: 5-15K (12) Large: >15K (11)

a. Based on Carnegie Classifications [28]

b. The one "spec/eng" institution was grouped Master's based on degrees available at the institution.

c. All doctoral institutions were RU/VH, except for one RU/H.

Based on the number of bachelor's degrees awarded nationwide by discipline for the 2013-2014 academic year, the examined population of degree programs characterizes the experience of 23% of computer science graduates (for programs inside engineering colleges) and 30% of computer and electrical engineering graduates [29]. Graduation data were not available for the seven studied computer science programs that were offered outside of engineering colleges.

As of March 2016, this sampling represents 6% of the total number of four-year ABET-accredited programs in computer science and 13% of accredited computer engineering programs [30]. Although the coursework data for this study was based on the 2013-2014 academic year, these 2016 percentages provide a reference point for the scope of the study since retroactive counts were not available on ABET's site.

A. Curricular Choice

To delineate curricular choice for each degree program, data for two course choice opportunity metrics were gathered from the 2013-2014 online university catalog. The first metric was the percentage of total degree credit hours that were free electives ("percent free electives")—meaning that no restrictions were placed on the course selections; students were free to choose any course. The second metric was the percentage of total degree credit hours that offered students a choice in the course they could take ("percent total choice"); these choices could include free electives, technical electives, humanities electives, etc., or simply getting to pick a writing class from two options.

B. Curricular Balance

For each degree program, curricular balance data was also gathered from the university catalog, including the total percentage of the degree program that consisted of required technical coursework ("technical"), the percentage of required non-technical coursework ("non-technical"), and the total possible percentage of non-technical coursework ("possible non-technical"). For this study, technical was defined as coursework in engineering, math and natural science, and non-technical was coursework outside of engineering, math, and natural science.

C. Comparators

To provide a meaningful context for the computer science and engineering curricular delineation, curricular choice and balance data for electrical engineering and bachelor's of arts and/or bachelor's of science chemistry, math and physics degree programs from the same 35 universities were also delineated. Electrical engineering was chosen due to its shared roots with computer science and engineering, and the chosen STEM comparators provide a sense of the curricular opportunities and experiences in related, non-engineering programs. Across the 35 universities, a total of 36 electrical engineering programs were present, including one B.A. program (at a university that also offered an EAC-accredited B.S. in electrical engineering); all but two of the 36 were EAC-accredited. Three of the 35 universities had an engineering focus and did not offer the non-engineering programs of interest; across the 32 remaining universities, a total of 121 non-engineering STEM comparator programs were present, including 39 chemistry (B.S.=25, B.A.=14), 39 math (B.S.=24, B.A.=15), and 43 physics (B.S.=25, B.A.=18) programs.

Sixteen of the institutions offered both computer science and computer engineering degrees, providing a subset of data for curricular choice and balance comparisons between the two program types.

D. Statistical Analyses, Software, and Data Presentation

Data collection and calculations were performed using Microsoft® Excel® 2013. The data for this study were ordinal, based on counts; as such, non-parametric Mann-Whitney U tests conducted in MVPstats were used to detect statistically significant differences between two independent samples of ordinal data with a two-tailed significance level of $\alpha=0.05$.

Box-and-whisker plots are used to present the data, displaying the median (the center of the box), the first quartile (lower extent of the box), third quartile (upper extent of the box), and maximum (upper extent of whisker) and minimum (lower extent of whisker). In some cases, statistical outliers extend beyond the whiskers.

IV. RESULTS AND DISCUSSION

A. Choice in Computer Science and Computer Engineering Programs

The degree of choice afforded to students in computing programs varied widely. Across the 62 programs, computer science and computer engineering students were afforded a median of 3% of their degree programs as free electives and were offered some choice in 49% of their total course selections (Fig. 1). Twenty-one of the programs (34%) offered students zero free elective opportunities, including 15 computer engineering programs and six computer science programs. In contrast, some programs included significant opportunities for choice, including two programs that provided 28-29% of the curriculum as free electives and seven programs in which more than 80% of the curriculum permitted some degree of choice.

For comparison, across the same 35 universities, engineering students in other disciplines were provided less choice, with a median of just 1% free electives and choice in 39% of their courses (electrical engineering: free electives=2%, total choice=44%). Seventeen of the 35 universities offered their engineering students a median of zero free electives. In contrast, at the median, the non-engineering STEM comparator programs offered students considerably more choice: 17% free electives (chemistry=16%, math=22%, physics=15%) and choice in 67% of their course selections (chemistry=59%, math=76%, physics =64%).

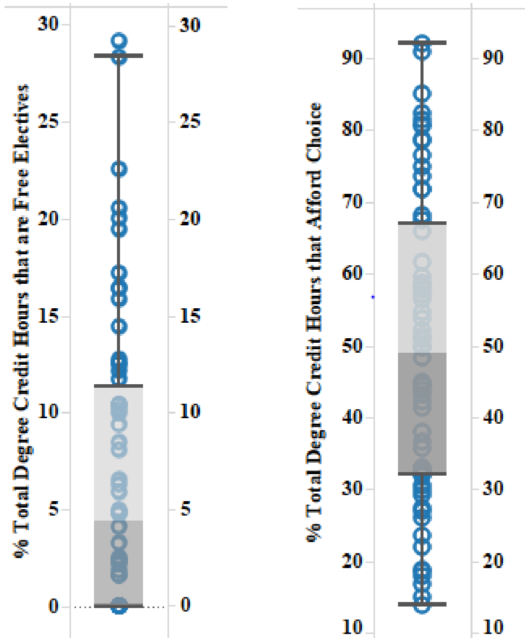

Fig. 1. Percent free electives and percent total choice for 62 undergraduate computer science and computer engineering programs.

The spread of data points for both free electives and total choice in Fig. 1 demonstrates that a wide range of course choice opportunity exists across the examined computing programs. This range of course choice opportunity is likely widened by differentiated curricular models for the different computing program types. For example, at the 16 institutions with both a computer science and computer engineering degree, the computer science programs afforded students with more choice: the median free elective choice was 7% in computer science versus 2% in computer engineering, and the median total choice was 53% in computer science versus 38% in computer engineering. The course choice opportunity differences across computing program types are further explored in the next section of this paper.

The lower choice across universities in computer science and engineering was exacerbated by higher total credit requirements; for example, a median of 131 for computer engineering and 127 for computer science, but only 121 for math majors (at the 16 institutions). Taken together, lower choice and higher total requirements likely limits in-migration to computer engineering degrees and also makes on-time, four-year graduation timelines more difficult to achieve.

B. Comparing Choice Between Computing Program Types

Table II presents median choice values for the 27 EAC-accredited computer engineering programs in contrast to the 14 CAC-accredited computer science programs and the 34 EAC-accredited electrical engineering programs; choice values for the 17 non-accredited computer science programs were also compared to the 121 chemistry, math, and physics comparators.

TABLE II. MEDIAN CHOICE PERCENTAGES AND MANN-WHITNEY U P-VALUES

Degree Program Category	% Free Electives	% Total Choice
EAC-accredited computer eng. (n=27) CAC-accredited computer science (n=14)	2 7 $^{.063}$	33 56 $^{.003}$
EAC-accredited computer eng. (n=27) EAC-accredited electrical eng. (n=34)	2 1 $^{.988}$	33 42 $^{.053}$
Non-accredited computer science (n=17) chemistry, math, physics (n=121)	13 17 $^{.000}$	73 67 $^{.261}$

[d] Superscripts are the sig. (2-tailed).

The findings shown in Table II indicate that, at the median, more curricular choice was afforded to the computer science students (56% for accredited programs, 73% for non-accredited programs) than the computer engineering students (33% for accredited programs); total choice for the computer engineering programs was comparable to that of the electrical engineering programs. Students in accredited computing programs experienced less total choice than their peers in chemistry, math, and physics; however, the total choice for students in non-accredited computer science programs and chemistry, math, and physics programs was comparable.

At the median, students in the non-accredited computer science programs were afforded with considerably more free elective opportunities (13%) than students in accredited computer science (7%) and accredited computer engineering (2%) programs; however, these students were still permitted fewer free elective opportunities than their peers in chemistry, math and physics majors (17%).

The four programs with the highest percent free electives were the four B.A. computer science programs (29%, 28%, 23%, 20%, respectively); the highest free elective percentage for a CAC-accredited computer science program was 17%; the highest free elective percentage for an EAC-accredited computer engineering program was 16%. Notably, the second-highest total choice value (91%) corresponded to an EAC- and CAC-accredited computer science and engineering program. These programs with exceptionally high choice opportunity demonstrate that it is possible to provide students with considerable curricular choice across each of the computing program types.

C. Curricular Balance

The 62 computer science and computer engineering programs studied required a median of 74% technical coursework (engineering, math, and natural science) and 23% non-technical coursework (Fig. 2). Through the use of free electives, it was possible for students in these programs to increase their non-technical coursework to a median of 27% of their total degree programs. However, the curricular balance was quite variable, ranging from 38% to 85% technical coursework. In five programs, less than 50% of the degree credit hours required technical coursework.

For comparison, the electrical engineering programs from the same universities had similar curricular balance requirements and opportunities; these engineering programs required a median of 74% technical coursework and 21% non-technical coursework, and students could take up to 26% non-technical coursework if desired. At the median, the 121 non-engineering STEM comparator programs required less technical coursework (chemistry=54%, math=47%, physics=58%; overall=53%), more non-technical coursework (chemistry=25%, math=27%, physics=26%; overall=26%), and students had more opportunity to increase their non-technical program content through the use of free electives (medians of chemistry=46%, math=53%, physics=42%; overall=47% possible non-technical coursework).

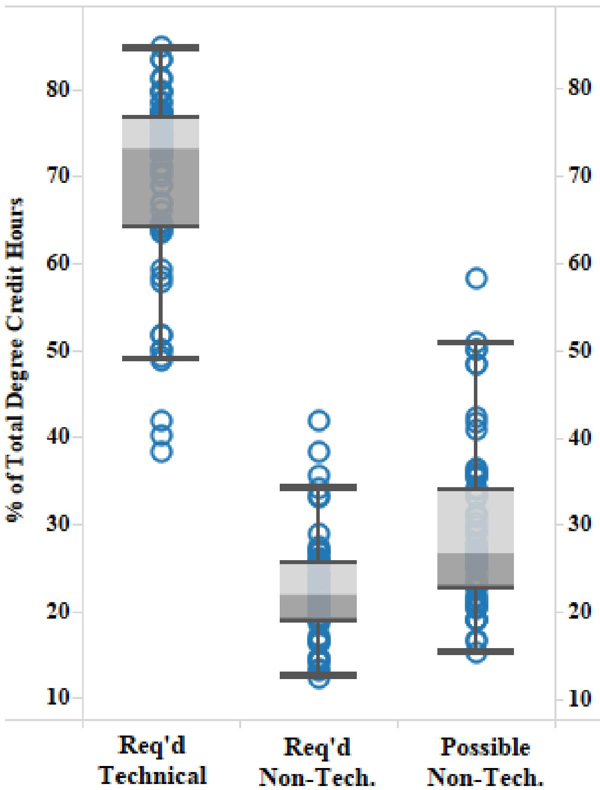

Fig. 2. Percent required technical, required non-technical, and possible non-technical coursework for 62 undergraduate computer science and computer engineering programs.

As with course choice opportunity, the spread of data points for the curricular balance metrics in Fig. 2 demonstrates that a range of technical—non-technical balance requirements and opportunity exists across the studied computing programs. At the 16 institutions with both computer engineering and computer science programs, the median technical requirements were 75% for computer engineering and 71% for computer science.

D. *Comparing Curricular Balance Between Computing Program Types*

Table III presents median curricular balance values for the 27 EAC-accredited computer engineering programs in contrast to the 14 CAC-accredited computer science programs and the 34 EAC-accredited electrical engineering programs; choice values for the 17 non-accredited computer science programs were also compared to the 121 chemistry, math, and physics comparators.

TABLE III. MEDIAN CURRICULAR BALANCE PERCENTAGES AND MANN-WHITNEY U P-VALUES

Degree Program Category	% Required Technical	% Required Non-Technical	% Possible Non-Tech
EAC-accred. comp. (n=27) CAC-accred. comp. (n=14)	75 69 $^{.019}$	21 25 $^{.043}$	24 32 $^{.000}$
EAC-accred. comp. (n=27) EAC-accred. elec. eng. (n=34)	75 75 $^{.875}$	21 21 $^{.783}$	24 25 $^{.454}$
Non-accred. comp. (n=17) chem., math, physics (n=121)	59 53 $^{.000}$	22 26 $^{.002}$	36 47 $^{.000}$

[e.] Superscripts are the sig. (2-tailed).

The results provided in Table III indicate that the computer engineering programs required students to take more technical coursework and less non-technical coursework than both the accredited and non-accredited computer science programs; the curricular balance requirements for these EAC-accredited computer engineering programs mirrored those of the EAC-accredited electrical engineering programs. At the median, the non-accredited computer science programs required considerably less technical coursework (59%) than the accredited computer science programs (69%) and the accredited computer engineering programs (75%), however the technical coursework requirement for non-accredited computer science programs was still higher than the median required for chemistry, math, and physics majors (53%). The non-technical coursework requirements varied less (21%-25%) across computing program types. Due to fewer free elective opportunities, however, the computer engineering students were more limited in the maximum portion of their degree programs that could be devoted to non-technical coursework (a median of 24%) compared to accredited and non-accredited computer science programs (medians of 32% and 36%, respectively).

Although EAC accreditation criteria requires only 62.5% technical coursework, the examined EAC-accredited computer engineering programs required a minimum of 69% technical coursework. The lowest technical coursework requirement for a CAC-accredited computer science program was 42%; this program was exactly balanced in terms of technical—non-technical requirements, also requiring 42% non-technical coursework, and provided significant room for academic exploration and choice through 16% free electives. The four B.A. computer science programs required 50-58% technical coursework and 20-25% non-technical coursework, though students in these programs could increase their non-technical coursework up to 42-50% of their degree programs if desired.

Generally speaking across the studied population of computing programs, the computer engineering programs were the least balanced in terms of technical and non-technical coursework requirements and opportunities; more curricular balance was made available in the computer science programs, especially those non-accredited and/or bachelor's of arts programs.

V. Summary and Conclusions

The results from this study indicate that, like their engineering peers in other disciplines, computer science and computer engineering students tend to experience less curricular choice and balance than their natural science and math peers. The results were stratified with respect to computing program type; for the metrics of interest, the EAC-accredited computer engineering programs were analogous to other engineering programs (specifically electrical engineering), while the non-accredited B.A. programs were more similar to the chemistry, math, and physics programs.

Offering multiple computing degree program options at a given university was somewhat commonplace: 16 of the studied universities (45%) offered both computer science and computer engineering degree program options to their students, including two universities that offered computer engineering and both B.S. and B.A. computer science programs. Providing multiple and different computing program options at a university might help to facilitate a diverse population of students with broad interests in satisfying their individual interests and needs. At universities with large disparities in the total degree program credits required for graduation, and higher credit hour requirements for their computer engineering students, providing another computing option with fewer total credits and more choice could encourage computing in-migration and participation.

The outcomes-based and flexible EAC- and CAC-accreditation criteria facilitate the implementation of diverse and choice-rich curricular models. And, exceptional accredited and highly regarded computer science and computer engineering programs exist that provide students with considerable curricular choice and opportunities for more curricular balance. These exceptional programs serve as examples of flexible, customizable and balanced degree programs in computer science and engineering. Additionally, these programs should prompt educators to assess curriculum across all computing program types through the lens of satisfying students' psychological and developmental needs, appealing to a broader sector of students, and reflecting evolving societal needs that call for more diverse graduates and more graduates with diverse and multifaceted knowledge and skill sets.

These results should be considered in context, remembering that the examined programs represent only a small sampling of all available computer science and engineering programs nationwide, and that the data were comprised of program curricular snapshots based on one catalog year; these program curricula may change over time. Furthermore, the extent to which curricular choice opportunities impact student attraction, satisfaction and success is unknown, as is the optimal amount of choice, before it becomes overwhelming and psychologically paralyzing [31]. These unknowns present areas of interest for future work. Does increased curricular choice and flexibility in computing and engineering programs broaden participation and/or improve quantifiable educational outcomes, such as performance, persistence, and time to graduation?

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