Broadening Participation in Computing via Ubiquitous Combined Majors (CS+X)

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ABSTRACT

In 2001, Khoury College of Computer Sciences at Northeastern University created their first combined majors with Cognitive Psychology, Mathematics and Physics. This type of degree has often been referred to as “CS+X” in the literature and is increasingly relevant as the need for interdisciplinary computer scientists grows. As of 2021, students at Northeastern can choose among three computing majors (Computer Science, Data Science or Cybersecurity) and 42 combined majors, which combine one of the three computing degrees with one of 29 distinct majors in other fields. Prior to 2014, combined majors were with the sciences, business and design. Over the last seven years, we created 29 new combined majors, explicitly creating combinations with fields where there has traditionally been greater gender diversity. The resulting increase in student interest and gender diversity over the last seven years is compelling. As of Fall 2020, 44.6% of the 2,800+ computing majors at Northeastern are pursuing combined majors, 39% of whom are women. This is substantially higher than the 21.5% reported in IPEDS for 2019 women computing graduates in the U.S. We did not observe any significant differences in racial and ethnic diversity between combined and computing only degrees. In this experience paper, we describe how we create and manage combined majors, and we present results on enrollments, admissions, graduation, internship placements, and how students discover combined majors.

KEYWORDS

BPC, Interdisciplinary Computing, CS+X

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1 INTRODUCTION

Increasing diversity in computing is an important and pressing goal, with numerous initiatives in government, industry, and education all focused on bringing in people from populations that have been historically marginalized in computing.[1] At the university undergraduate level, one key component of such initiatives has been attracting a more diverse population of students to major in computer science. Interdisciplinary computing has been shown to be one method for broadening participation in computing [11]. Additionally, as computing becomes increasingly relevant to all areas [10], creating interdisciplinary computing degrees becomes increasingly important.

In 2001, the Computer Science college at Northeastern created their first combined majors with cognitive psychology, mathematics and physics. A *combined major* offers the opportunity for intense study in two disciplines. Students take nine courses in each discipline, at least one integrative course and a capstone course, which further integrates the two disciplines. This type of degree has often been referred to as “CS+X” when one of them is a computing discipline [15]. As of Fall 2021, students at Northeastern can chose among three computing disciplines (computer science (CS), data science (DS), or cybersecurity (CY)) and 42 combined majors, which combine one of the three computing disciplines with one of 29 disciplines in other fields.[2]

[1]Historically marginalized populations in computing include women, Black/African American, Hispanic/LatinX, American Indian/Alaska Native, Native Hawaiian/other Pacific Islander, and people with disabilities.
[2]*https://www.khoury.northeastern.edu/programs/* shows the descriptions and degree requirements for each combined major.

The original motivation for creating combined majors at Northeastern relates to its history as a co-op school, where students interleave study with practical, paid work experience. A student who wished to *double* major would not be able to graduate on time and fully avail themselves of the co-op program. Such students would be forced to choose between (a) going on one fewer co-op (a deeply unpopular choice) or (b) spending longer in school (increasing their education costs). Double majoring also dramatically reduces the number of free electives. Combined majors provided a solution, because at Northeastern, combined majors require nine courses in each of the two disciplines and 2+ integrative courses, thereby enabling students to fully avail themselves of the co-op program and to graduate on time. In contrast, Khoury's within-discipline majors require 14-16 computing courses.

Beginning in 2014, we began to respond to the need for interdisciplinary computing majors because of the increasing applicability of computing to all fields. In addition, we recognized the potential to increase gender diversity by creating combined majors with disciplines that have historically been more gender diverse than computing. And thus over the last seven years, we created 29 new combined majors. The resulting increase in student interest in combined majors and gender diversity since 2014 are stunning. As of Fall 2020, 44.6% of computing majors are pursuing a combined major at Northeastern; of these, 39% are women. This is significantly greater than the numbers reported in the IPEDS data for CIP-Code 11, which reports that 21.5% of CS graduates in the U.S. were women in 2019 [19]. Indeed, at Northeastern only 21% of within-discipline computing majors are women.[3] In terms of race and ethnicity, we have not observed a statistically significant difference in the representation in race and/or ethnicity in combined versus non-combined majors at Northeastern. We also examined the representation when looking at the intersection of race/ethnicity and gender and again did not observe any overall trends.

In this paper, we first describe how we create a new combined major with another unit at the university, including a discussion of the curriculum, plan of study, advising, and how we convey the availability and relevance of combined majors to prospective and current students. We then present the gender distribution and popularity of each combined major, along with the job placement outcomes of combined versus within-discipline computing majors. We discuss the common barriers that may need to be addressed in most universities to implement combined majors, and we conclude with a summary of their impact at Northeastern.

2 INTERDISCIPLINARY COMPUTING

In this section, we discuss the opportunities that combined majors provide and place them in the context of interdisciplinary computing. The opportunities are:

(1) Combined computing majors address the increasing need for computing knowledge and skills across all disciplines.
(2) A computing combined major has the potental to increase a student's employability [17].
(3) Employers have the opportunity to hire students trained in two fields that are both relevant to the company (e.g., pharmaceutical companies might prefer a DS/chemistry combined major to a DS major alone).
(4) The computing department/college can alleviate some of the pressure from booming enrollments by reducing the number of requirements to obtain a computing degree [15].
(5) Interdisciplinary computing has been shown to broaden participation in computing; in particular, to increase the percentage of women [11].

Interdisciplinary majors, minors and courses are often touted as a way to attract women to computing, particularly from fields that attract higher proportions of women, such as biology [11, 12]. Indeed, Sax et al. [18] observed that women were more likely than men to pursue a double major with computing.

Researchers and practitioners have suggested that by contextualizing computing as a problem-solving tool applicable to many fields, students will be more inclined to see the computing discipline's value [4, 8]. Indeed, much of the research on interdisciplinary efforts in computing focuses on the introductory courses [1, 3, 6, 7, 9, 13, 16, 20]. However, the extent to which students pursue longer-term interdisciplinary efforts after the introductory courses is unknown [12]. Barr [1] observed that that through the introduction of interdisciplinary courses in the intro sequence that women's representation in the major increased from 10% to 37% over the course of 10 years, and further that the rate at which women and men leave the introductory courses is the same (a rate not observed at many universities [5]).

Several colleges and universities have created one or more interdisciplinary majors (CS+X) such as Colby College, College of Charleston, Lewis University, Occidental College, Union College, the University of Illinois at Urbana-Champaign, and the University of Kansas. Additionally, many universities are implementing DS degrees that require a substantive set of courses from one or more units outside of computing.

3 IMPLEMENTATION

In order to understand the implementation details, it is necessary to understand how Northeastern is structured. The university is divided into seven colleges for full-time undergraduate students: a College of Engineering (COE), a College of Science (COS), a College of Social Sciences and Humanities (CSSH), a College of Art and Design (CAMD), a College of Health Sciences (Bouvé), a College of Business (DMSB), and a College of Computing (Khoury).

Workflow: Developing combined majors at Northeastern is the responsibility of the associate dean of undergraduate programs, who works together with the Khoury faculty and the faculty from the other unit to define the degree requirements and shepherd the new degree through university governance. Note that in addition to the 42 combined degrees with computing, there are currently 120 combined degrees that do *not* include Khoury. Indeed as combined majors proliferate within a university, the ease of creation increases. For example, Northeastern's governance for a combined degree requires approval from each unit, each home college's curriculum committee, and the university's undergraduate curriculum committee. This is a simplified process relative to *core* majors, which

[3]Note that in these summary statistics we include combined majors with Computer Engineering as majoring *within* the computing discipline. If we count them as combined majors then the percentage of our students doing combined majors rises to 50.4%.

Table 1: The requirements of an example combined degree: Computer Science and Design. Note that prerequisites and general education requirements are not included.

College	Course
Khoury	*Discrete Structures*
Khoury	*Programming 1*
Khoury	*Programming 2*
Khoury	*Algorithms and Data*
Khoury	*Object-Oriented Programming*
Khoury	*Software Development*
Khoury	2 Upper-level Khoury electives
CAMD	*Color and Composition*
CAMD	Choose one of {*Form and Structure*, *Movement and Time*, *Experience and Interaction*}
CAMD	*Design Process Context and Systems*
CAMD	*Typography 1*
CAMD	*Typography 2*
CAMD	*Information Design*
CAMD	Upper-level Design elective
Khoury	*Human Computer Interaction* (integrative)
CAMD	*Design Capstone* (integrative)

additionally require approval by the faculty senate, the provost, and the board of trustees.

To make the creation of combined degrees less work on faculty both within Khoury and in other units, Khoury has created three rough templates for degree requirements; one for each of our three majors (CS, DS, CY). On a practical level, most partner units have responded positively to our preemptive drafting of a combined degree. Using the predetermined templates and a "best guess" of the partner's disciplinary requirements (based on the partner's existing core requirements) allows both departments to focus on selection of higher-level electives, appropriate interdisciplinary courses, and capstone courses. As of 2021, most units in the university have now created their own templates, because many of their requirements will carry over regardless of combined discipline.

Curriculum: A combined degree between unit M and unit P at Northeastern consists of required courses from unit M, required courses from unit P, integrative courses and a capstone course. All degrees within the computing template have foundational programming requirements (e.g., the standard *Programming 1*, *Data Structures*, *Object-Oriented Programming*, *Discrete Structures* and *Algorithms*). Upper-level electives are customized depending on the partner discipline and best interdisciplinary fit. For example, the CS/game development degree requires *Programming in C++*, *Building Game Engines*, and *Game AI*. Similarly, the CS/English degree features three elective tracks as well as *Natural Language Processing* and *Programming Languages* requirements.

A university requirement of *any* combined degree is that it must contain at least one "integrative" course. These are sometimes existing courses, and sometimes are created when the combined degree is created. For example, the DS/business administration degree requires *Data-Driven and Technology-Enabled Value Creation in Digital Economy*, the CS/English degree requires *Technologies of Text*, and the CY/criminal justice degree requires *Law, Ethics, and Policy of Data and Digital Technologies*. For some combinations, we have created and require more than one integrative course; e.g., for CS/media arts degree we require both *Computer Graphics* and *Human–Computer Interaction*. Either unit can provide the integrative course(s), and in some cases it is co-designed and co-taught. See Table 1 for a specific example of a combined degree. Note that Table 1 does not show general education requirements, or the math requirements for the CS degree (all computing degrees require *Discrete Structures* and *Calculus I*, while some require several additional higher-level mathematics including *Calculus 2*, *Statistics and Probability* and *Linear Algebra*).

A "plan of study" is required at the creation of the degree as proof of concept (and critical for passing through university governance). The plan shows a student's progression through the degree requirements semester-by-semester, and accounts for prerequisite chains and course offering schedules. The university's advisors then work with students individually to modify the plan based on individual circumstances (e.g., AP or transfer credits) and goals (e.g., minors, study abroad, number of co-op experiences).

Advising: Currently, majors that are combined with CS, CY, or DS are all managed and advised by the Khoury unit with the exception of majors combined with COE. At Northeastern, students are advised using a professional advising model with each college managing their own academic advising team. Students are assigned to an advisor randomly without regard to major and maintain the same advisor during their time at Khoury. To stay current on curricula outside of Khoury each advisor is assigned a liaison role to another college. The liaison meets regularly with their assigned college's advising staff and trains all other Khoury advisors about updates regarding the combined majors with that college. This continual training allows for all advisors to support all majors and enables students to have one advisor for their whole time at Khoury.

4 RESULTS

We now present the growth of combined majors both in the number offered, their increasing popularity and the resulting increase in gender diversity in computing. We also present a brief summary of career outcomes for combined versus non-combined computing majors.

Growth of Combined Majors: At Northeastern, prospective students can apply to a major directly and current students are permitted to change to any major. If during admission, a student is undecided they will apply as "undeclared" students, but this represents less than 8% of the first year class. Many students begin university as a non-combined major and either switch majors completely or change to being a combined major. All combined majors are described on the undergraduate marketing materials and websites of both colleges/departments. Additionally, Khoury academic advising runs workshops for first-year students to introduce them to combined majors at the beginning of each academic year. We examined how students became combined computing majors to determine whether students discovered combined majors before or after applying to Northeastern and found that for students enrolled

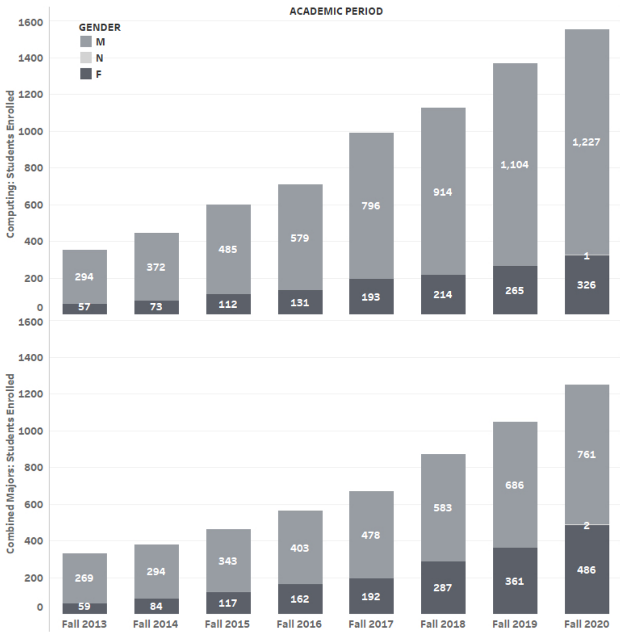

Figure 1: Enrollments of undergraduates who identify as male (M), female (F), non-binary (N) for computing-only majors (top-graph) and combined majors (bottom graph).

as combined computing majors in Fall 2020: 57% enrolled in the combined computing major directly as a first year/transfer student; 16% enrolled as a non-combined computing major, and then changed to a combined major; and 27% enrolled as a non-computing major, and then changed to combine that major with CS/DS/CY (e.g., they came in as a biology major and then changed to DS/biology).

Figure 1 shows the growth in popularity of combined majors over the last seven years. In the figure we report both the number of computing-only and combined majors, and the representation of women/men/non-binary in each. As can be observed from the figure, the overall growth in combined and within-discipline computing majors has seen a threefold increase. In both we see growth in the representation of women: for within-discipline computing we went from 16% women majors in 2014 to 21% in 2020 (we include CS/CE in the within-discipline statistics); and for combined over the same period we went from 18% to 39% women. Note that as Barr [2] points out, when comparing the change in the percentage of women in CS longitudinally it is more accurate to divide the number women CS majors by the number of women students in the university; however in our case, men and women are about 50-50 in the university so a direct comparison is appropriate.

In Table 2 we show data for each combined major. Each row shows the name of the other unit, the year we created the combined major, the total number of students, and the percentage of women for each of the three possible Khoury degrees. Note that if the year is blank then that means there is no combined major (e.g., as of Fall 2021, journalism can be combined with CS and DS, but not CY). In some cases, we have a combined degree but no enrollment because the degree was created so recently that students have not yet declared it as a major (e.g., CS/theatre was just created, and the data was pulled from 2020 enrollments). We collected but do not show the race and ethnic data because we observed no significant differences between combined versus non-combined majors for any race or ethnicity. The results for women are significantly different. Combined majors have a higher representation of women than non-combined majors with the exception of DS.

Finally in Table 3 we report the number of graduates, incoming students and applications for the combined degrees by college. Note that for the graduation data many numbers are zero because those majors are so new, no student has had time to graduate yet (e.g., combined majors with DS and CY were created after 2018 and 2019, respectively). The population of incoming combined majors for Fall 2021 is 46% women, in contrast to 23% for CS and 22% for CS/CE). It is also important to note that the increase in gender diversity was not achieved by "leaning in" to women applicants; roughly the same percentage incoming students who are women is the same as the overall percentage of women who applied. An interesting observation is that for 2021 the percentage of women applicants who applied to within-discipline DS and CY is higher than for CS.

Co-op Placements: An important question is whether students who complete combined majors are more or less successful in landing a job after graduation. We examined co-op placement for combined versus within-discipline computing majors as a proxy for job outcomes after graduation (students are not required to tell us where they take a job). Note that in university-wide survey data, 98% of all Northeastern graduates have a job or are in graduate school within nine months of graduation. We examined the results for Spring 2019 and Fall 2019 (we did not look at 2020 because of the impact of COVID-19). We divide the number of students placed by those who are actively searching for the semester (defined as a student who submits 10+ resumes a week until they have landed a position). Of the 445 combined and 504 within-discipline active searchers, roughly 90% were placed in a co-op position; there was no difference in the placement of combined versus within-discipline majors.

Combined majors might choose to do one co-op in tech and one in the other discipline. For example, a CS/biology combined major completed their first co-op as a software developer at local hospital, combining a love of tech within a medical setting. The student's second co-op focused on the biology side as a bioassay scientist for a start-up that enables industrial, academic and clinical scientists to develop and use multiplexed assays on standard laboratory instrumentation. Upon graduation, the student entered a Ph.D. program in computational biology.

5 IMPLEMENTATION CHALLENGES

In this section we discuss the barriers to implementation that we faced at Northeastern and that other institutions might face. In each case we present the challenge followed by a possible solution.

University Budget Model: Combining majors both within or across schools/colleges at a university can have implications on both units' budget, which can generate resistance to creating combined majors [5]. In particular for a Responsibility Centered Management

Table 2: Combined majors with CS, DS, and CY. For each we show the year of creation, the college of the other major, the total number of students in Fall of 2020, and the percentage of those students who identify as women.

Other Major	College	Computer Science			Data Science			Cybersecurity		
		Year	Students	% Women	Year	Students	% Women	Year	Students	% Women
Design	CAMD	2006	110	71.8						
Communication Studies	CAMD	2014	11	27.3						
Game Development	CAMD	2010	103	20.4						
Journalism	CAMD	2011	4	75.0	2019	1	100.0			
Media Arts	CAMD	2008	33	57.6						
Music Comp. and Tech.	CAMD	2006	32	25.0						
Theatre	CAMD	2021								
Business Administration	DMSB	2006	308	26.6	2019	46	45.7	2018	10	10.0
Health Sciences	Bouvé				2018	8	75.0			
Behavioral Neuroscience	COS	2020	5	60.0	2019	17	70.6			
Biochemistry	COS				2018	13	69.2			
Biology	COS	2005	54	46.3	2019	8	50.0			
Chemistry	COS				2021					
Cognitive Psychology	COS	2001	82	61.0						
Ecology and Evol. Bio.	COS				2019	1	100.0			
Environmental Science	COS	2009	8	62.5	2019	2	0.0			
Linguistics	COS	2016	22	54.6	2020					
Mathematics	COS	2001	189	24.3	2019	18	50.0			
Physics	COS	2001	48	20.8	2020					
Psychology	COS				2019	4	75.0			
Criminal Justice	CSSH	2016	10	80.0				2018	12	41.7
Economics	CSSH	2017	59	33.9	2020	3	33.3	2018	2	0.0
English	CSSH	2016	5	60.0						
History	CSSH	2016	3	33.3						
Philosophy	CSSH	2016	20	20.0						
Political Science	CSSH	2017	16	25.0						
Sociology	CSSH	2016	5	100.0						
Chemical Engineering	COE	2021								
Civil Engineering	COE	2021								
Computer Engineering	COE	2014	322	15.8						
Computing	Khoury	1982	1035	20.5	2018	97	30.9	2019	99	32.3

Table 3: For all combined majors within each college at Northeastern, we show the graduates, incoming majors and applicants for Fall 2021. Note that more than 92% of students declare their major upon entering Northeastern. For each category we show both the total number of students and the percentage who identify as women.

College	2021 Graduates						2021 Incoming Students						Fall 2021 Applicants					
	CS		DS		CY		CS		DS		CY		CS		DS		CY	
CAMD	52	46.1	0	0.0			89	46.1	1	0.0			731	42.1	5	40.0		
DMSB	59	27.1	4	25.0	1	0.0	73	45.2	28	39.3	3	100.0	516	38.0	169	37.3	45	60.0
Bouvé			0	0.0					3	100.0				.	68	69.1		
COS	70	28.6	0	0.0			125	40.8	37	59.5			1566	39.2	482	47.3		
CSSH	18	33.3	0	0.0	0	0.0	37	40.5	13	46.2	8	75.0	440	40.2	85	40.0	60	46.7
COE	54	11.1					54	22.2					1322	23.7				
Khoury	182	15.4	17	17.6	14	28.6	289	23.2	12	50.0	19	42.1	2748	26.0	239	38.1	105	52.4

(RCM)[4] budget model, there may be a direct financial disincentive to creating combined majors. Even in a non-RCM budget model, money follows enrollments (albeit more slowly), which might mean that other deans or department chairs may resist any action that will lead to a further growth in computing enrollments.

Creating a combined major with another unit requires the agreement of the dean of that college along with the willingness of the

[4]RCM means that a unit's budget directly follows enrollment; i.e., in a given year, the school/college/department, receives all or a part of their budget directly tied to the revenues from enrollment for that year.

department within that college. The budget model at Northeastern is a hybrid RCM model, in which revenue to a unit is based on course enrollments and the number of majors. Specifically, if a student who is majoring in M takes a class in unit M, all tuition revenue is assigned to M.[5] If a student majoring in P takes a course in unit M, then the tuition revenue is split evenly between M and P. For combined majors, the splits are calculated as follows. If a combined major between M and P takes a course in either M or P the tuition revenue is split 50-50 between M and P. If the combined major takes a course in unit Q, then the tuition revenue is split as follows: 50% to Q, 25% to P and 25% to M. Thus neither P nor M is penalized in terms of tuition revenue from combined majors. *We found this to be crucial to getting buy-in from other units.*

Because a unit's budget follows enrollments, other units in the university may be unwilling to further add to the popularity of computing, which has risen to be one of the most popular undergraduate majors in the U.S. A possible motivation for combined majors can be that for majors in areas for which enrollments may be decreasing, combining degrees with computing may result in *increased* enrollments; and further combining a computing major with another area can lead to increased employability of graduates (and likely higher salaries for alumni) [17].

Combining with Accredited Degrees: Creating a combined major with a unit that has an accredited degree[6] has its own challenges. These are typically professional degrees such as architecture, engineering, nursing and physical therapy (PT). For nursing, PT and architecture, lack of flexibility in the required plan of study dictates that a student could complete a minor in computing, but a combined major would not be feasible without adding significant time to degree completion. For engineering, ABET accreditation [14] reduces the ability to adjust requirements to create a holistic combined major; indeed, the math/science requirements account for 30 credits out of the required 120 to graduate. Despite this challenge, in 2014, we launched the first combined degree of CS/computer engineering. Fitting two disciplinary requirements and ABET requirements resulted in a limit of two general electives for students. These electives must cover all university level course distribution requirements. The result is that students must bring in significant AP or transfer credit to finish the degree in a timely manner. Two additional engineering combined majors were created in 2021 (CS/chemical engineering and CS/civil engineering.).

Administrative Unit: Because a combined degree will span two administrative units in a university, a decision must be made as to which unit is a student's "home unit." At Northeastern, the home unit dictates the name of the college on the degree. As a practical requirement, home unit dictates responsibility in terms of both university metrics (retention rates, graduation rates) and student interface (academic/career advisors).

Historically, at Northeastern, Khoury has retained home unit for all combined majors except for those with COE, which needed to be the home unit to manage ABET requirements. Because the majority of computing combined majors choose to work in the tech industry, the career preparation class provides technical interviewing and resume preparation for the tech industry. The designation of Khoury as the home unit created some political challenges, where other units felt like they did not get "credit" for their combined majors.[7] In Fall 2022, Northeastern is moving to letting each student chose their home college. Although some aspects of this third challenge may be unique to Northeastern, the issue of which unit provides academic/career advising needs to be resolved in a university before implementing combined majors.

Faculty Time and Advisor Training: A roadblock to creating combined degrees is the increasingly limited bandwidth of computing faculty caused by rapidly increasing enrollments, and the challenges with faculty hiring in the last few years. However, because combined majors require fewer computing courses than computing-only majors, combined majors can be an avenue to reducing the enrollment pressure on upper-level computing courses. If a college/university has faculty advisors this can also increase the complexity of their advising as combined majors proliferate.

Agreeing to "give up" part of your requirements: When both units want to retain most if not all of their within-discipline major requirements, it may lead to set of requirements that are really no different than a double major. Note that at liberal arts colleges, a double major with integrative courses and encouragement from faculty and advising to consider double majoring can serve the same purpose as combined majors. A particular challenge is faced in computing departments that sit inside of another college that has it's own extra set of requirements such as engineering which may require several science courses or humanities which may have a substantial foreign language requirement. This can make it difficult to satisfy all general education, college-specific, and combined major requirements, which may add time to degree.

6 CONCLUSIONS

This experience paper presented the results of a 20 year journey; we did not create 42 combined majors overnight. Enrollment in 2020 shows that 44.6% of computing majors are pursuing combined majors and 39% of combined computing majors are women. The percentage of women is increasing as can be seen from Table 3 which reports application and enrollment data for Fall of 2021. The population of incoming combined majors for Fall of 2021 is 46% women in contrast to 23% for within-discipline computing majors. We anticipate that with the growth of DS and Cyber, both of which were recently introduced, that these percentages will rise even further. Indeed, for the incoming class for Fall 2021 50% of DS majors and 42% of Cyber majors are women. Given that computing is increasingly relevant to all disciplines, combined majors can increase both the diversity of thought and the representation of computing graduates who identify as women.

[5] It is actually a fraction of the tuition as tuition is split between the unit and central.
[6] At Northeastern, we have chosen not to apply for CAC ABET accreditation.
[7] Note that at Northeastern, the home college is actually penalized because of the need to provide advising support for the increased head count without increased revenue.

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