Removing a Barrier: Analysis of the Impact of Removing Calculus and Physics from CS on Employability, Salary, and Broadening Participation

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ABSTRACT

This study was designed to compare salary implications and employability of students who graduated with a Bachelor of Arts in Computer Science (BACS) – *primarily distinguished by the removal of calculus and physics requirements* from the traditional computer science curriculum versus those that graduated with a Bachelor of Science in Computer Science (BSCS). Given the numerous studies that identify gateway courses like calculus and physics as impediments to students' persistence in engineering and computer science AND their impact on women and people of color, the removal of this barrier has incredible potential for broadening participation in computing. One university's first cohort of BACS graduates (spring 2020) furnished a unique opportunity to compare student's self-reported employment and salary information to their BSCS peers. The study consisted of institutional data and a survey targeting spring 2020, summer 2020, fall 2020 graduates from computer science, with data from n=134 recent graduates (BA n= 45, BS n=89). Preliminary results indicate there are no statistical significance in enrollment on the basis of gender nor job attainment; however, there is a statistical significance in enrollment on the basis of race/ethnicity and pay. The results of this work could either serve as a cautionary tale for institutions considering similar programs OR it could serve as the basis for a deeper, more critical review of the requirements currently in place in BSCS programs, nationally. Are calculus and physics courses required for prosperity in computing or are they simply a barrier to equity?

CCS CONCEPTS

• **Social and professional topics → Computer science education**.

KEYWORDS

Computing education, Computer science education, Undergraduate curriculum; Broadening participation

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1 INTRODUCTION - THE PROBLEM

Dating as far back as 1981, scholars have debated the necessity for "so much" mathematics in computer science curricula [23]. Ralston [23] went as far as to say, "while mathematics may be good for the soul (and maybe for the mind also), it has little direct relevance to undergraduate computer science" (p. 475). In fact Ralston, along with others [10] made the argument that while mathematics had a major role in the development of the computer science discipline and likely influenced the magnitude of math required, it was no longer necessary [24]. At most, they believed that computer science should have one calculus class (if at all) in the third year but should otherwise, have a computer science grounded discrete mathematics course instead [7, 23, 24]. There are, of course, others on the other side of this argument that believe that computer science has taken a turn towards the "math-phobic" and that this trend should be reversed [3, 27]. That even though there seems to be a loose coupling between math and practicing developers, mathematical reasoning complements computer science reasoning and thus should not be separated [2]. No matter which side of the argument you stand on, it is hard to ignore the impact the math-intensive computer science programs have on maintaining the cycle of exclusivity in computing [8, 12]. This exclusivity has prompted a call to the community to consider alternative pathways for those wishing to enter computing that see the requirements of calculus as a barrier [10]. This study presents the case of one university that heeded this call by designing and offering a Bachelor of Arts in Computer Science that removed the calculus and physics requirements (but retained discrete mathematics and statistics) with a specific interest

in the impact curricula decisions for this alternative pathway had on students' enrollment trends, employability and salary potential. In this study we answer the following research questions:

(1) What are the trends in enrollment for the BACS and BSCS?
(2) What are the differences in enrollment on the basis of race/ethnicity and gender?
(3) Are there implications for employability of students graduating with a BACS vs. BSCS?
(4) Are there implications for salary of students that graduate with a BACS vs. BSCS?

2 RELATED RESEARCH

2.1 Math in Computer Science

Over the last forty years computer science has grappled with the role math plays in the curriculum [23]. The role of calculus, specifically, has been met with great debate about its appropriateness. Add to that the demands of accrediting boards and universities are stuck trying to navigate this quagmire and make decisions appropriate for their institutional context [1]. Prior analysis of universities across the country have demonstrated inconsistency with regards to math requirements, ranging from one math course to eight [2]. Couple that with inconsistent results from studies that are split on the implications of strong math prowess and success in computing courses and administrators and curriculum committees are stuck with a tough decision [9, 16, 29]. Does calculus stay or should it be removed? Should it be paired down or should we ramp up?

2.2 Math as a Barrier to Representation in Computer Science

In recent years, computer science has tried to reckon the perceived exclusive nature of the discipline by diversifying participation. This has resulted in a wealth of literature aimed at understanding and unpacking means of *broadening participation in computing* [6, 11, 15, 25, 28]. Bringing to bare the inequities in the broader U.S. education system, and how it falls short of preparing Black, Hispanic, and Indigenous populations for computing, engineering, or any math-intensive fields [14]. Combine these findings with those that highlight courses like calculus as *barrier courses* [26] or *bottlenecks* in both computer science and engineering [5] for all students and problematic to women's pursuit of these fields due to years of stereotypes and negative feelings towards math [18, 19] and suddenly calculus - a course identified by some as not relevant - is an exclusionary variable.

3 THEORETICAL FRAMING

For this study, we used *relational choice theory* to frame our work. Relational choice theory is rooted in economics and sociology and provides a lens for understanding a student's *cost benefit analysis of the alternatives* [4, 13] when considering pursuit of a discipline. The idea is that a student will weigh whether their expectation of success is low and the costs of trying are high and use that to determine which path to choose [4]. For this work, the choice is between the BACS and the BSCS. For this manuscript we are only sharing enrollment trends, employability, and salary results but we thought it was important to share context about the framing of the study.

Survey Questions
(1) Which degree program have you pursued?
(2) Are you Hispanic or Latinx?
(3) Choose one or more races that you consider yourself to be.
(4) What is your gender?
(5) Have you received any job offers related to your degree?
(6) What is your starting salary?

Table 1: Sample Survey Questions

4 SETTING

The setting for this study is a large minority serving metropolitan university with a computer science department that serves approximately 2000 computer science students. After years of grappling with low graduation rates the department conducted a careful review of the curriculum and revealed two things: 1) none of the required courses in the Bachelor of Science computer science curriculum had Calculus as a pre-requisite; and 2) that students recognized this and selected their course trajectory with this information in mind. In fact, a large portion of the student population was delaying their completion of Calculus I, II, Physics I, and II because of this realization. This prompted the department to take a bold step in 2017 by launching a Bachelor of Arts in Computer Science degree that presented a pathway through computer science for students. More specifically, it removed the requirements of Calculus I and II and Physics I and II from the curriculum. It should be noted that they retained Statistics and Discrete Mathematics requirements. A cursory look at enrollment trends inspired the question - could this pathway broaden participation?

5 METHOD

For this study we used two data sets - (1) institutional data to analyze enrollment trends overall and on the basis of race/ethnicity, and gender (RQ 1-2); (2) survey data collected from recent or near graduating BACS and BSCS students from one institution (RQ 3-4).

Taking the research questions into consideration we collaborated with the institutional accountability office to look at enrollment trends and in addition we developed a survey to elicit demographic data related to race, ethnicity, and gender as well as degree program (BA or BS), job offer, and starting salary for recent graduates. The survey was then reviewed by other lab members for content validity and readability (see Table 1). The questions were imported into Qualtrics and were administered electronically.

Through IRB and administrative approval students that met the inclusion criteria - having recently graduated from the institution in Spring 2020, Summer 2020, and Fall 2020 and were enrolled in either program were emailed (366 students) of which n=134 participants (BA n= 45, BS n=89) completed the survey (36% response rate). The data were imported into R studio for analysis.

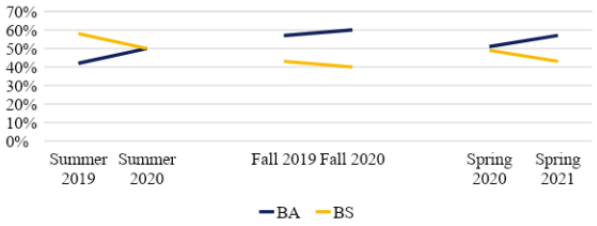

Figure 1: Computer Science BA and BS Enrollment Trends by Term

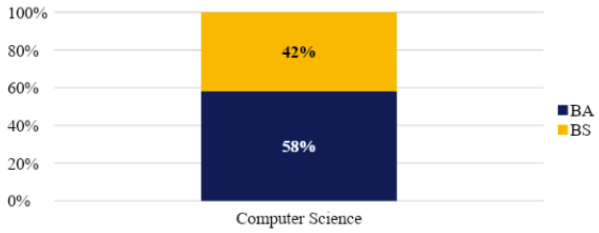

Figure 2: Computer Science BA and BS Enrollment

	BA		BS	
Gender	*n*	%	*n*	%
Female	303	59%	210	41%
Male	1167	58%	860	42%

Note: Includes only students from Spring 2020 through Spring 2021. $n = 2540$; $\chi^2 = 0.37$, $p = 0.54$

Table 2: Computer Science BA and BS enrollment by Gender

Figure 3: Computer Science BA and BS enrollment by Gender

		BA		BS			
Term	Gender	*n*	%	*n*	%		
Summer 2019	Female	84	47%	94	53%	2.59	0.11
	Male	350	41%	511	59%		
Fall 2019	Female	183	60%	121	40%	1.56	0.22
	Male	703	56%	547	44%		
Spring 2020	Female	157	52%	147	48%	0.08	0.80
	Male	659	51%	639	49%		
Summer 2020	Female	147	54%	127	46%	1.90	0.18
	Male	538	49%	560	51%		
Fall 2020	Female	227	64%	125	36%	3.25	0.08
	Male	880	59%	605	41%		
Spring 2021	Female	204	57%	152	43%	0.01	0.95
	Male	859	57%	647	43%		

Note: p is Fisher's Exact Test (2-sided)

Table 3: Computer Science BA and BS Enrollment by Gender and Term

6 DATA ANALYSIS

Descriptive statistics and inferential statistical procedures were used to determine enrollment trends and statistical significance between groups (gender and race/ethnicity). For comparisons between groups Fisher's Exact Test were used. Tables and figures that are disaggregated by term (Tables 3 and 5 or Figures 1, 4, and 6) have a "duplicated" headcount, where each student will appear multiple times if they enroll in multiple terms; tables and figures that do NOT disaggregate by term have "unduplicated" or unique headcount, where each student appears only once regardless of enrollment in multiple terms.

Similarly, descriptive statistics were used to determine demographics of the participants. And inferential statistical procedures were used to determine statistical significance between groups with regards to employability and salary. For data handling, the *job offer* question when left blank or unanswered were recoded as *no*. We made the assumption that if they did not answer the question, their answer was *no*. Likewise, for the salary question we recoded blanks or non-answers as *NA*. We used Fisher's Exact test for employability and Wilcoxon rank sum tests were used for salary analysis.

7 RESULTS

7.1 Impact on Enrollment

The addition of this new pathway resulted in immediate shifts in enrollment (see Figure 1). Institutional data from Summer 2019, Fall 2019, Spring 2020, Summer 2020, Fall 2020, and Spring 2021 demonstrates a consistent increase in BACS enrollment and decrease in BSCS from Summer 2019 through Spring 2021 (see Figure 1). This has resulted in a majority of current enrolled students declaring BACS (58%) as their intended major (see Figure 2). It should be noted that Figure 2 only includes enrollment from Spring 2020 through Spring 2021 and only counts each student once (students would likely be included multiple times in the dataset for Figure 1 if they enrolled in more than one of the semesters listed).

7.2 Impact on Enrollment on the Basis of Gender

Overall differences between male and female students in BA vs BS enrollment for Computer Science majors were very small and not statistically significant (Table 2). Comparing within each gender group, the proportion of BA vs BS majors is about the same, though there are about 4 times as many men enrolled compared to women. About 59% of women have enrolled in a BA program compared to 58% of men; this is not a significant difference in the overall rate (see Figure 3). There were no significant difference in BA vs BS enrollment between genders any term (see Table 3).

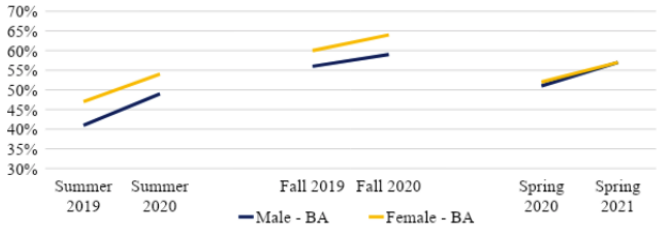

Figure 4: Computer Science BA and BS Enrollment Trends by Gender

		BA		BS	
Race/Ethnicity	Group	*n*	%	*n*	%
Hispanic	1	922	54%	777	46%
Black	2	206	76%	65	24%
White	2	167	70%	71	30%
Asian	1	72	52%	67	48%
Other	2	42	70%	18	30%
Nonresident Alien	1	48	41%	69	59%

Note: Includes students from Spring 2020 through Spring 2021. "Group" indicates ethnicities that have significantly different proportions of degree enrollment from one another (e.g., significant difference between Hispanic students [Group 1] compared to Black students [Group 2] but not between Hispanic and Asian students [both Group 1]). $n = 2524$; $\chi^2 = 83.42$, $p < .001$.

Table 4: Computer Science BA and BS Enrollment, Race/Ethnicity

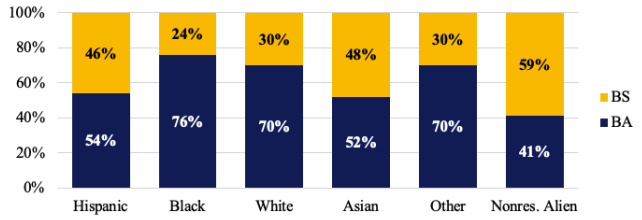

Figure 5: Computer Science BA and BS Enrollment, Race/Ethnicity

7.3 Impact on Enrollment on the Basis of Race/Ethnicity

Significant differences in BA vs BS enrollment between ethnic groups were apparent (see Table 4). In general, a larger percentage of Hispanic, Asian, and Nonresident Alien students were enrolled in the BS plan compared with other ethnic groups (see Table 4, and Figure 5).

The differences observed between ethnic groups has occurred in every semester. Enrollment in the BA program has increased over time for all ethnic groups except Asians and other ethnicities (Native Americans and Pacific Islanders) (see Figure 5).

		BA		BS			
Race/ Ethnicity	Grp	*n*	%	*n*	%	χ^2	*p*
Spring 2020							
Hispanic	1	536	49%	569	51%		
Black	2	101	70%	43	30%		
White	1,2	72	56%	56	44%		
Asian	1,3	41	46%	49	54%	38.68	<.01
Other	2,3	28	72%	11	28%		
Nonres.Alien	1	32	38%	52	62%		
Summer 2020							
Hispanic	1	440	47%	495	53%		
Black	2	99	71%	40	29%		
White	1,2	64	54%	54	46%		
Asian	1	35	43%	47	57%	44.40	<.001
Other	1,2	23	72%	9	28%		
Nonres.Alien	1	17	31%	37	69%		
Fall 2020							
Hispanic	1	710	57%	536	43%		
Black	2	147	78%	41	22%		
White	1,2	112	69%	51	31%		
Asian	1	61	58%	44	42%	44.8	<.001
Other	1,2	29	74%	10	26%		
Nonres.Alien	1	40	48%	43	52%		
Spring 2021							
Hispanic	1,3	661	53%	577	47%		
Black	2	153	76%	41=9	24%		
White	2	125	69%	56	31%		
Asian	3	50	48%	54	52%	65.86	<.001
Other	1,2	31	78%	9	22%		
Nonres.Alien	1,3	34	40%	50	60%		

Table 5: Computer Science BA and BS Enrollment by Race/Ethnicity and Term

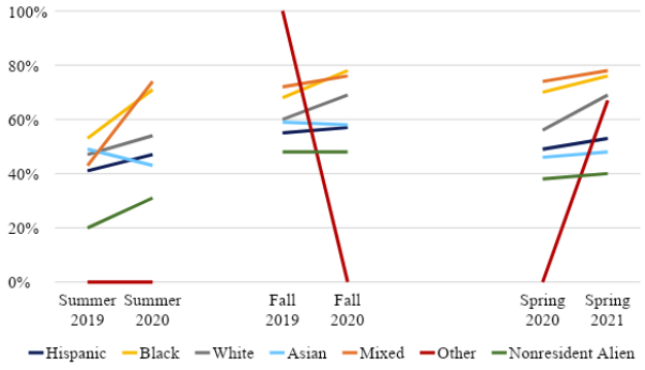

Figure 6: Computer Science BA Enrollment Trends, Race/Ethnicity

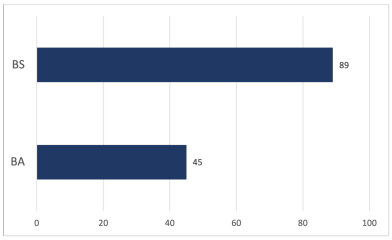

Figure 7: Survey Participant Major (%)

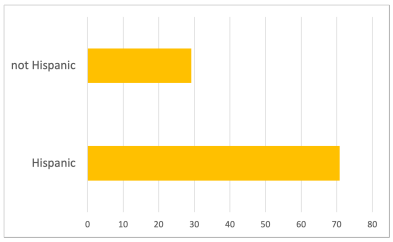

Figure 8: Survey Participant Ethnicity (%)

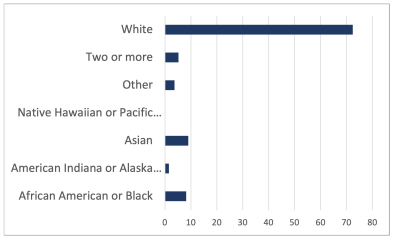

Figure 9: Survey Participant Race (%)

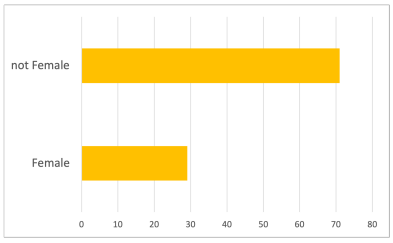

Figure 10: Survey Participant Gender (%)

7.4 Survey - Demographics

In addition to the institutional data, we collected demographics from our survey participants that included major (see Figure 6), ethnicity (see Figure 7), race (see Figure 8), and gender (see Figure 9). We had twice as many BS students complete the survey as BA students. Hispanics were overrepresented in the sample but in alignment with the student population overall, similar patterns were identified across race. In terms of gender we had more women participate in the study (29.1%) than are represented in the major (18%).

Job Offer	BA	BS	p
Yes	40%	47.1%	
No	60%	52.8%	0.4661

Table 6: Employability

Salary Range	BA	BS	p
<10000	0%	0%	
10001–19999	0%	2.2%	
20000–29999	2.2%	1.1%	
30000–39999	2.2%	0%	
40000–49999	4.4%	1.1%	
50000–59999	4.4%	4.5%	
60000–69999	11.1%	4.5%	
70000–79999	2.2%	5.6%	
80000–89999	0%	5.6%	
90000–99999	0%	1.1%	
>100000	8.9%	8.9%	
NA	64.4%	65.2%	2.2e-16

Table 7: Salary Implications

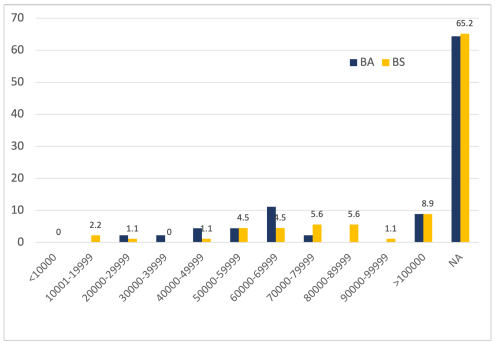

Figure 11: Salary Distribution

7.5 Employability and Salary Implications

We asked the students if they had received a job offer because we defined employabitlity as their ability to get a job, not whether they had accepted an offer. Of the n= 45 BA students that completed the survey, 40% indicated that they were able to secure a job (see Table 6). Likewise, of the n= 89 BS students that completed the survey, 47.1% indicated that they were able to secure a job (see Table 6). When comparing the two degree tracks we found that there was no statistical difference with regards to job offers received upon graduation (see Table 6). While there were no statistical significance in job offers, there was a statistical significance difference between BA and BS with regards to salary distribution. We present both the statistical difference (see Table 6) and the salary distribution between the two majors (Figure 10).

8 DISCUSSION

The establishment of a Bachelor of Arts in Computer Science degree program provided an alternative pathway for those seeking an occupation in computing that may have otherwise been deterred by the high attrition rates present in CS due to math and science proficiency [3]. This addition did result in decreased enrollments in the more traditional Bachelor of Science in Computer Science program. While there were slightly more women enrolled in the BA, the difference in program enrollment was not statistically significant. This is consistent with literature that suggests that women's lack of engagement with computing has little to do with mathematics [21]. However, there were significant differences across race/ethnicity. In fact, African American students enrolled in statistically significant higher rates, indicating that this new track has the potential to attract a more diverse population of students to the field.

This realization brought us to the second concern related to this alternative pathway - does this pathway create a road to broadening participation or does it further disadvantage minoritized populations? Based on the analysis related to employability and salary the results are mixed. There was no statistical difference between the BA and BS graduates ability to secure employment (or be offered a job). There was, however, a statistical difference in salary. This result could be an indicator that the removal of calculus and science have deleterious affects on students' financial mobility [17, 22] or may be an indication of the limitations of this degree pathway - students are relegated to specific computing professions that historically pay less [20].

Broadening participation in computing is a complex problem that is receiving a lot of attention from scholar and funding agencies to try to understand and address inequities in this prosperous field. Creating additional pathways is one way of opening up a field that has the reputation of being exclusive and elusive. Given the body of literature that identifies calculus and physics as *barrier courses* coupled with the lack of consensus within the discipline on the importance of calculus - removal of these courses appears, on the surface, to be a simple solution [24, 26]. When considering employability alone - removal of calculus and physics appears to present promise for broadening participation. However, further studies are encouraged to better understand this discrepancy in salary across the two majors. Computing is perceived by some as a means of closing the social mobility gap, not fulfilling that promise is something that students should know upfront to aid in decisions related to occupational pursuits and major choice.

9 LIMITATIONS OF THE STUDY

There are many limitations to this study, as it is still preliminary data. The job offer data may have been impacted by timing. At the time of the survey distribution students, were job hunting in the height of COVID. The less than 50% job rate for both pathways seems low under normal circumstances. There might also be effects due to the data being obtained by student response to surveys or even how soon the survey was administered relative to their graduation. It is also worth nothing that while the overall n from the survey was enough for advanced statistical analysis, when the data were disaggregated by major the numbers rapidly decreased limiting the type of analysis that could be conducted. We plan to expand the data collection further so that we can introduce linear regression to look for interaction effects between variables like gender and race/ethnicity - which could be impacting salary variation. We would plan to explore factors such as employment location - as our students tend to remain local, which can result in lower salaries AND job titles to deduce whether our BA students are accepting positions with lower salaries. We must also consider the implications of the choice of imputation of data. Anytime you impute data you gain (in n) but variables can get highly distorted and the variance underestimated. Another limitation to the study is that it was limited to one department at one university. In the future we would like to expand the study to include an expanded data set that includes a wider variety of institutions across the nation. We also plan to explore average and median salaries between the degree programs in comparison to other STEM and non-STEM majors to determine if the BA salaries are still more competitive and lucrative than other STEM or non-STEM majors.

10 CONCLUSION

The preliminary results of this work provides insight into the addition of an alternative computing pathway - Bachelor of Arts in Computer Science or, in this case, a less math intensive alternative to the traditional computer science undergraduate degree. This work indicates that it is an attractive option, as overall enrollment has steadily been on the incline. While it had little impact on women it appeared to be a much more attractive option for African-American and Hispanic identifying students which means it could be a means of broadening participation.

The mixed results on the impact on employability needs further exploration. The survey participants in this study were able to find employment, which is promising but the difference in salary is stark. However, in spite of this difference it might be that that this alternative pathway through computing (with lower starting salaries) is still likely to be better than had they pursued a non-CS major. Further work is necessary to better understand the motivations for electing one pathway (BA) over another (BS) (getting back to relational choice theory); the context around the salary discrepancy between the two majors; students' perceptions of their salary potential; and a better understanding of the implications as it relates to race/ethnicity and gender. Broadening participation in computing is a goal but not one we should achieve at the detriment of those we wish to bring into the fold.

The results of this work has implications for students that have aspirations of careers in computing, departments grappling with curriculum considerations, and for accrediting bodies that currently require as much as 15 credit hours (or the equivalent) of *mathematical rigor*. Depending on the institution, their dependency on accrediting bodies (like ABET) may discourage them from implementing such changes. It may be time to revisit the discussion around the role of calculus in computing going forward, especially if it is a barrier to broader participation that can be removed. More work is necessary to begin to tease out the benefits and implications of such curricular choices to help inform accrediting bodies and curriculum committees alike.

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