A Longitudinal View of Gender Balance in a Large Computer Science Program

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ABSTRACT

Computer Science has a persistent lack of women's participation. In order to best effect change, we require a more fine-grain analysis of the gender disparity as it changes throughout an undergraduate Computer Science curriculum.

In this paper, we use a quantitative approach to highlight, with greater specificity, the point in an undergraduate career where gender balance changes. We also examine the role of grades in students' decisions to stay in the course sequence. Our goal is to enable targeted interventions that will make Computer Science a more welcoming discipline.

Our study examines 30,890 unique student records over ten years at a large, public research institution. The records include students who took a Computer Science course over the past ten years. The dataset contains information about gender, majors, minors, academic level, and GPA. The dataset also includes a record from each course taken by each student and their final grade.

We observed a modest increase in women's participation in all Computer Science courses over the past ten years. Despite this increase, the gender disparity is still large. Through our analysis, we found that women consistently choose not to continue through the Computer Science sequence at a higher rate than men. This higher attrition could be linked to women receiving lower grades in most introductory CS courses despite having the same or higher GPAs than men.

Our results reveal specific areas where intervention can be the most effective in changing the stubborn gender disparity in Computer Science.

CCS CONCEPTS

• **Social and professional topics** → **Computer science education**; **Gender**; *Computer engineering education*;

KEYWORDS

Gender diversity; Women in computer science; CS1; CS2; CS3

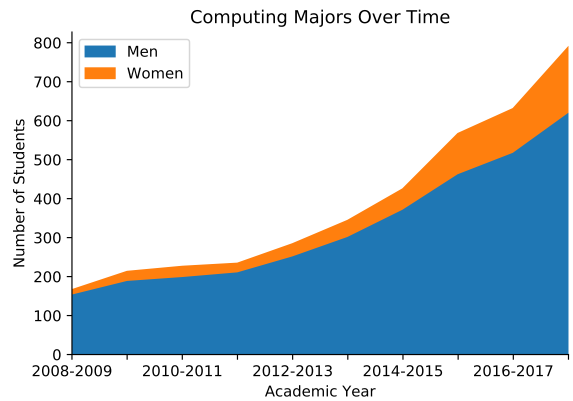

Figure 1: Computing Majors have increased dramatically over the past ten years. While the number of women has increased, they represent only 27.5% of recent majors.

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1 INTRODUCTION

Interest in computing undergraduate majors has increased dramatically over the past ten years. While the number of women majoring in Computer Science is increasing, institutions struggle to achieve true gender balance. This study takes a fine-grain, quantitative analysis of gender balance throughout the curriculum at a large, public research institution.

1.1 Background

Mirroring national trends [11], there has been a large growth in Computer Science over the past ten years. As seen in Figure 1, the number of students graduating with a computing major (defined in Section 2.4.1) has increased every year. While the number of women in computing has increased, gender balance in computing remains an issue as women are still significantly underrepresented.

Outside of computing, we see nearly equal gender balance. In the 2017-2018 academic year, 50.3% of undergraduate students were women and 49.7% were men. In the same period, women made up only 27.5% of undergraduates in computing majors. While there have been improvements in computing gender balance, a large discrepancy remains.

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1.2 Related Work

Gender balance in the computing field remains a problem today despite the continued focus on the discrepancy between the number of participating men and women. There may be more women interested in the computing field but many do not complete a degree. One study found that women were twice as likely to consider leaving a CS major as compared to men [7]. Even if they choose to stay, many women do not move to take an industry or academic job in the computing field [2, 9].

Researchers have pointed to several reasons as to why women do not persist in the computing field. They have noted that students who leave the major tend to have the perception of the major being asocial, having no connection to the outside world, and lacking interest in human interaction [3, 4]. Many people do not identify with this culture. Specifically, many women and underrepresented minorities feel out of place and as if they do not belong which causes them to leave the field [6].

In addition to the lack of sense of belonging, women have much lower confidence than men when it comes to computing. Even women who major in computing still have lower confidence working with computers than men who are not majoring in computing [3]. With this lack of self-confidence, many women choose to leave despite having potential in the field.

Knowing why students leave computing programs is important. Equally important, however, is why students, particularly women and underrepresented minorities, stay. Several authors have pointed to distinct factors that contribute to a student's decision to stay in the program. Some of which include peer and particularly same-sex student interaction, pace and workload of classes, prior experience, and faculty encouragement, among others [1, 5, 6, 10].

Many have suggested that student-student interaction, particularly with the same sex, is the most important contributing factor as to why women stay in the computing field [1, 5, 10]. This suggests that programs should make student-student interaction a core part of their curriculum and stop relying on extracurriculars to host these crucial interactions.

Another often cited reason of women stay in computing is faculty encouragement. Cohoon suggests that faculty encouragement is almost as important as having same-sex peers [5]. However, other studies have suggested that faculty have little to no impact on women persisting [10].

Despite the increase of women in STEM overall, women are still less likely than men to work in STEM after receiving a STEM degree [2]. This is particularly interesting as both women and men share their interest in entrepreneurship and women show even more interest in management than men [8]. This trend also extends to the academic computing field and not just to industry [9].

Prior work has explored why women leave Computer Science programs at higher rates than men. Furthermore, these studies point to specific reasons for the departure of women and suggest interventions to alleviate the problem. To maximize the impact of interventions aimed at improving gender balance in Computer Science, we need to know when the greatest changes in gender balance occur in a curriculum.

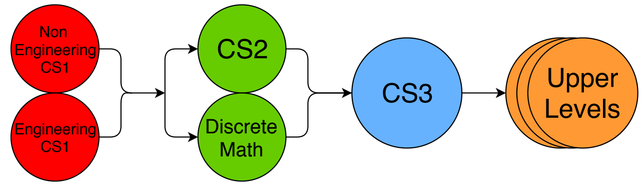


Figure 2: Introductory Course Sequence, starting with CS1, then CS2 and Discrete Mathematics, and CS3 (Data Structures and Algorithms). Followed by Upper Level courses.

1.3 Research questions

In this study we examine each course in an introductory Computer Science sequence to gain a detailed view of gender balance. Specifically, we explore:

- Where in the Computer Science curriculum does the gender balance change?
- Do grades play a role in this change?

2 METHODS

The subject of our study is a Computer Science curriculum at a large, public research institution. We provide details about curriculum, dataset, statistical methods, and special definitions of terms used throughout the paper.

2.1 Curriculum Overview

This study focuses on the introductory Computer Science sequence at one large, public research institution. Figure 2 shows a high-level, visual overview of this sequence.

All students begin with introductory programming, which we refer to as CS1. This course is offered in two different variations: one for engineering students focusing on C++ and Matlab and a second for non-engineering students focusing on C++ and Python. Both variations are rigorous courses which introduce students to programming for the first time and teach fundamentals. Following CS1, students take CS2, Programming and Introductory Data Structures. In CS2, students learn additional programming paradigms and begin studying data structures. Additionally, students take Discrete Mathematics before moving on to CS3 (Data Structures and Algorithms). After completing these four introductory courses, students begin to take Upper Level Electives. Electives include Operating Systems, Web Systems, Machine Learning, Computer Security, and many others.

Instructors in each of CS1, CS2, Discrete Math, and CS3 vary from semester to semester. Additionally, instructors can vary within several sections of one course in one semester. However, instructors coordinate between sections and semesters to provide a uniform experience for all students, regardless of section or semester. All courses are taught in a traditional lecture-style classroom setting, with an accompanying discussion section or laboratory.

2.2 Dataset

Our dataset is derived from official university records. It includes demographic information, as well as semester course work and grades. From this dataset, we extracted records of 30,890 unique students who took at least one CS course during the ten years between fall semester 2008 and fall semester 2018. The dataset includes an anonymous unique identifier, gender, majors and minors received for each student. It contains a record for each class taken by each student, with the academic level of the student at that time, their cumulative grade point average, and their final grade in the course.

Initial analysis of the growth of computing majors over the past ten years revealed significant growth, as shown in Figure 1. Since the number of computing majors changed significantly over the past ten years, the past five years of data are more representative of the state of the computing program today. Thus, our further analyses include only the most recent five years of data, reducing our dataset from 30,890 to 21,351 student records.

2.3 Statistical Methods

We used several statistical methods to verify our findings. Specifically, we used two-sided t-tests, chi-squared tests, and one ANOVA test to verify significance. The t-tests tested differences between the average grades of men and women in particular classes and differences between cumulative grade point averages. The chi-squared tests tested differences between withdrawal, fail, and attrition rates between men and women. Finally, the ANOVA test tested for a relationship between gender, grades, and whether or not a student moves on in the sequence.

2.4 Special Definitions

2.4.1 Computing Majors. We refer to computing majors in this paper as the group of majors of Computer Science, Data Science, and Computing Engineering. The Computer Science and Data Science majors are offered through both the college of engineering and non-engineering. The Computer Engineering major is only offered through the college of engineering. Computer Engineering students are required to take CS1, CS2, and Discrete Math and may elect to take CS3 and Upper Level CS Electives. Data Science students are required to take CS1, CS2, Discrete Math, and CS3 and some Upper Level CS Electives. Computer Science students are required to complete the entire sequence shown in Figure 2 and explained in Section 2.1.

2.4.2 Attrition Rate. We calculated attrition rate as the rate at which a group does not take the next course in the sequence within four semesters from when they took the original course. A semester in this case counts as a Fall, Winter, or a half term Spring semester. For example, say the attrition rate of men in CS2 in Fall of 2016 was 30%. This indicates that of the men who passed CS2 in the Fall of 2016, 30% did not take CS3 during or before the Winter of 2018. We chose four semesters as the cut off because we found that around 93% of students take the next course in the sequence within four semesters.

3 RESULTS

In this section, we analyze potential reasons for changes in gender balance. The analyses include differences in attrition rates, withdrawal rates, failure rates, and grades. Additionally, we include one multivariate analysis of grades, gender, and attrition rates.

	Mean Attrition		
Class	**Women**	**Men**	**P-Value**
Non-Engineering CS1*	57.5%	47.6%	3.26e-11
Engineering CS1*	71.7%	57.1%	8.55e-23
CS2*	34.5%	26.4%	1.98e-07
Discrete Math*	25.6%	16.4%	4.82e-10
CS3	9.1%	10.0%	5.16e-01

Table 1: Attrition Rate, results of chi-squared tests for differences between attrition rates in men and women for each course in the CS sequence that have a preceding course. * indicates statistical significance ($p < 0.05$).

3.1 Attrition Rates

Our first results come from an analysis of attrition rates disaggregated by gender. Attrition is the rate at which a group of students does not move on in the course sequence within four semesters. A more in depth definition with an example can be found in Section 2.4.2.

The attrition rates for CS1, CS2, and CS3 are visually displayed in Figure 3. The graphs display average attrition rates from 2013 to 2017. They do not display data past this as students who took a class after the Winter of 2017 have not yet had a full four semesters of opportunity to take the next course in the sequence. Thus the attrition rates for those semesters are not yet valid. Engineering CS1 and Discrete Math are not pictured as they have very similar rates to non-engineering CS1 and CS2 respectively.

Attrition rates early in the sequence start off high for both genders and decrease moving forward in the sequence. In all courses but CS3, women have statistically significant higher attrition rates than men meaning that on average, women choose to not move on to the next course in the sequence at a higher rate.

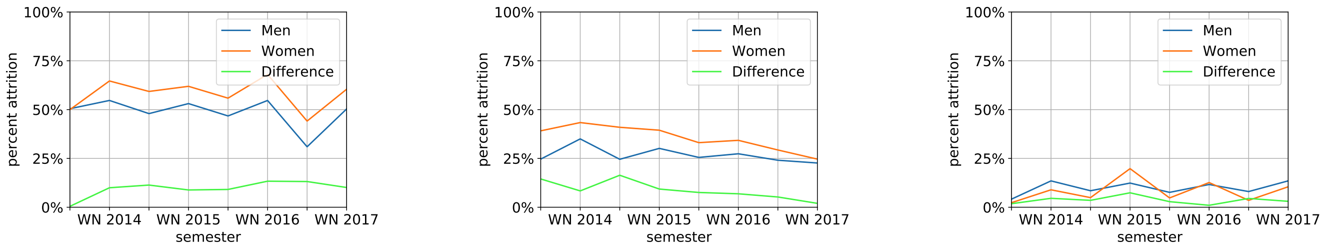
The results from each course's statistical analysis can be found in Table 1. The statistical analysis included chi-squared tests for each class to test differences in attrition rates between men and women. For each course, the independent variable was gender and the dependent variable was the attrition rate.

The green line in the graphs displayed in Figure 3 represents the difference between the attrition rates of the genders. If the program had achieved true gender balance, this line should be hovering at 0% difference.

3.2 Withdrawal Rates

In our next analysis, we examined withdrawal rates disaggregated by gender. We did a chi-square test for each class to test for significant differences of mean withdrawal between men and women. For each course, the independent variable was the gender and the dependent variable was the withdrawal rate. The results of this statistical analysis is shown in Table 2.

We found that women withdraw at a statistically significant higher rate than men over the past five years in non-engineering CS1, CS2, and CS3. For the others, engineering CS1, Discrete Math, and Upper Level courses, there was no significant difference between withdrawal rates. Even though there are differences in half of the courses, the differences in the means are at most 2.2%.



(a) Non-engineering CS1

(b) CS2

(c) CS3

Figure 3: Attrition Rates by course, percent of students that do not move on to the next course in the sequence each semester, by gender. Women tend to have higher attrition rates than men. Attrition in both genders generally decreases as the course sequence progresses while the difference between the attrition rates of men and women stay generally consistent until CS3.

	Mean Withdrawal		
Class	**Women**	**Men**	**P-Value**
Non-Engineering CS1*	8.1%	6.7%	0.026
Engineering CS1	1.3%	1.2%	0.753
CS2*	7.5%	5.6%	0.001
Discrete Math	7.5%	6.2%	0.106
CS3*	9.5%	7.3%	0.013
Upper Levels	3.1%	3.1%	0.877

Table 2: Withdrawal Rates, results of chi-squared tests for differences between withdrawal rates in men and women for each course in the CS sequence. * indicates statistical significance ($p < 0.05$).

3.3 Failure Rates

Next, we examined failure rates disaggregated by gender. Figure 4 shows the average failure rates of men and women in every semester from 2013 to 2018 for CS3. As shown in Figure 4 and in the subsequent statistical analysis in Table 3, there is no indication of women failing more than men and thus being forced out of the course sequence. The statistical analysis included chi-squared tests for each class to test differences in failure rates between men and women. For each course, the independent variable was gender and the dependent variable was the failure rate. In non-engineering CS1, CS2, and Upper Level courses, there is a significant difference in the failure rates between men and women. However, as shown by the means in Table 3, men are failing more than women. In all other courses, engineering CS1, Discrete Math, and CS3, there is no statistically significant difference between the failure rates of men and women.

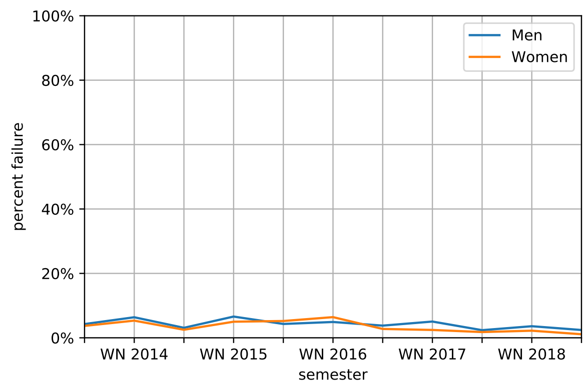


Figure 4: Failure Rates in CS3, by gender.

	Mean Failure		
Class	**Women**	**Men**	**P-Value**
Non-Engineering CS1*	2.6%	3.5%	0.030
Engineering CS1	2.5%	2.3%	0.677
CS2*	1.8%	3.1%	0.002
Discrete Math	5.3%	4.2%	0.051
CS3	3.2%	4.1%	0.142
Upper Levels*	1.9%	3.0%	0.001

Table 3: Failure Rates, results of chi-squared tests for differences between failure rates in men and women for each course in the CS sequence. * indicates statistical significance ($p < 0.05$).

3.4 Grades

Figure 5 and Figure 6 show the grade distribution for CS2 and Upper Level courses respectively over the last five years. Engineering CS1, CS2, Discrete Math, and CS3 all have significant differences between the average grade of men and the average grade of women. The other courses in the sequence, non-engineering CS1 and Upper Level courses, are dissimilar to CS2's distribution as there is no significant difference between the average grades of men and the average grades of women. Full results from the statistical analysis can be found in Table 4. The statistical analysis included chi-squared tests for each class to test differences in mean grade received between men and women. For each course, the independent variable was gender and the dependent variable was grade received.

Figure 5 and Figure 6 show grades specific to CS courses. Figure 7 shows the cumulative GPA of engineering and non-engineering

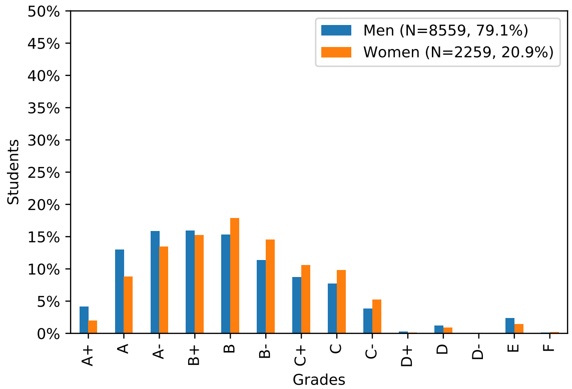


Figure 5: Grade Distribution in CS2, by gender.

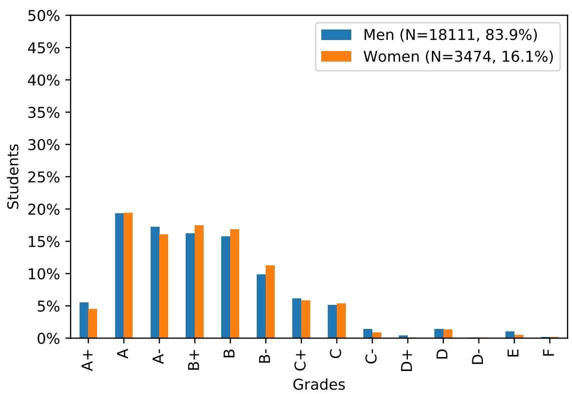


Figure 6: Average Grade Distribution in Upper Level Courses, by gender.

	Mean Grades		
Class	**Women**	**Men**	**P-Value**
Non-Engineering CS1	3.35	3.32	1.14e-01
Engineering CS1*	3.44	3.52	4.10e-06
CS2*	2.95	3.06	5.56e-07
Discrete Math*	2.89	3.01	8.68e-07
CS3*	2.90	3.01	1.84e-05
Upper Levels	3.23	3.23	8.24e-01

Table 4: Grade Discrepancy, results of two sided t-tests for differences between grades received by men and women for each course in the CS sequence. Grades are on a 4.0 GPA scale. * indicates statistical significance (p < 0.05).

majors disaggregated by gender. Through six two-sided t-tests, we found that there was no statistically significant difference between the mean cumulative GPAs of engineering men, engineering women, and non-engineering women. However, there was a statistically significant difference between each of these three

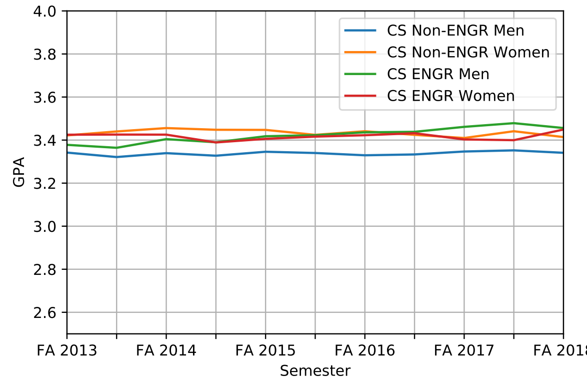


Figure 7: Average Cumulative GPA Over Time, divided by Engineering vs. Non-engineering and gender.

	df	SS	MS	F Stat	P-Value
Discrete Math	1.0	45.92	45.92	229.89	3.79e-51
CS2	1.0	45.11	45.11	225.85	2.72e-50
Gender	1.0	3.75	3.75	18.76	1.50e-05
Residual	7264.0	1451.00	0.20		

Table 5: Effects on Attrition, results of ANOVA test for Discrete Math grades, CS2 grades, and gender's relationship to attrition rates. Grades have the largest impact but gender independent of grades also has an impact.

groups and non-engineering men's mean cumulative GPAs with non-engineering men having lower cumulative GPAs on average than the other three groups.

3.5 Effects on Attrition Rates

Table 5 shows the results of an ANOVA test on the relationship between a student's Discrete Math grade, CS2 grade, and gender on the student's decision to move on to CS3. Only students who passed both Discrete Math and CS2 were included in this test. We chose to focus this test only on the movement from the CS2 level to CS3 because this is where we saw both a grade disparity and an attrition rate disparity in both classes.

The results show that grades of both classes have the largest effect on a student's decision to advance to CS3. They also show that gender does have an effect even when controlling for grades in Discrete Math and CS2.

4 DISCUSSION

In this section, we will discuss the results of our analysis of gender and attrition rates, withdrawal rates, failure rates, and grades.

4.1 Attrition Rates

We found that the attrition rate generally decreases as the course sequence progresses. In the introductory level CS1 course, we expect that many students, if not most, will not take CS2 or Discrete

Math. As students move through the course sequence they become more committed and thus we see a decrease in attrition rates.

The more interesting observation is the difference between the attrition rates of men and women. Women, despite passing the course, do not to go on to the next class in the sequence at a statistically significant higher rate than men. This is the case for CS1, Discrete Math, and CS2 but is not the case for CS3. Once students reach CS3, a large majority of them, regardless of gender, move on to take Upper Level courses. In the cases where the attrition rate does differ, the means between the genders differ by 14.6% in engineering CS1, 9.2% in Discrete Math, and 8.1% in CS2.

This large difference in attrition begs the question, why are women choosing not to go on, particularly in courses before CS3?

4.2 Failure and Withdrawal Rates

We did not find evidence that women are failing out of the CS sequence. As described in Section 3.3, men and women either fail at the same rate or women fail at a lower rate than men.

We found statistically significant differences in withdrawal rates in some classes but not others. Differences in withdrawal rates between men and women could partly explain the lack of women in CS courses. In the non-engineering CS1 course, CS2, and CS3, there is a significant difference between the withdrawal rates of men and women with women withdrawing at a higher rate than men. In all other courses, engineering CS1, Discrete Math, and Upper Level courses, there is no significant difference in withdrawal rates.

This difference in withdrawal rates could be a contributor to the lack of women in CS but it is likely not a large contributor. Compared to other factors such as voluntary attrition rates and grades, the magnitude of the difference in withdrawal rates is not great. Additionally, the difference only exists in half of the courses in the sequence. The largest difference comes in CS3 with around a 2% difference in withdrawal rate means. This is an order of magnitude lower than the differences we see in attrition rates. Due to this, we focused more on the attrition rate differences. However, it is important to note that there is a small difference in the withdrawal rates of men and women.

It is interesting to note that in CS2 and non-engineering CS1, men are failing more than women but women are withdrawing more than men. This may point to a difference in how men and women handle adversity in CS courses. If a student begins to do poorly in a CS course, their reaction to their performance may differ depending on their gender. Perhaps women will withdrawal prematurely when they might have passed the course in the end. Perhaps men do not withdraw when they are in danger of failing, resulting in more men failing.

4.3 Grades

Grades could be a reason why women are choosing not to remain in CS. In engineering CS1, CS2, Discrete Math, and CS3, women receive lower grades than men. The largest differences come in CS3 and in Discrete Math where grades can differ as much as 0.11 of a grade point. Although this is less than the difference between the grade of a A- to a B+, it could have the effect of pushing a student to the next highest letter grade.

From the findings that women received lower grades than men, we could conclude that grades are reflective of a gender group's abilities and that women simply do not perform well in rigorous technical courses. However, both engineering and non-engineering women have equally high average cumulative grade point averages as engineering men and higher average grade point averages than non-engineering men. So women are performing just as well, if not better than men in all other non-CS courses. From this we may ask, why are women receiving lower grades in these courses but not others? This is a question for future research.

4.4 Effects on Attrition Rates

We observed that grades are not the only factor in a student's decision to advance to CS3. Gender, independent of any grade received, has an effect on whether or not the student moves on to CS3. This suggests that even in the absence of a grade disparity, gender imbalance would still exist. We observed that grades do have the largest effect on a student's decision to move on. Therefore, eliminating the grade disparity will improve gender balance but it would not bring the balance to equality. There are other factors which impact a student's decision to advance that we have not yet analyzed.

5 CONCLUSIONS AND FUTURE WORK

This study examined gender balance in a large CS program over ten years, with the goal of identifying opportunities for maximum impact. Although we observed a modest increase in women in this program over ten years, there is still a lack of women continuing through the entire program. We observed a disparity in attrition rates in CS1, CS2, and Discrete Math, which suggests the problem lies in classes that come before CS3 in the introductory sequence.

Why are women choosing not to move on in the sequence, particularly in courses before CS3? We attempted to answer this question through the analysis of grades. We observed a grade disparity in those classes and observed that grades have the largest association with a student's decision to move on from CS2 and Discrete Math to CS3. Our results suggest that this institution could focus efforts to reduce the gender imbalance in CS by working to eliminate the grade disparity in CS2 and Discrete Math. The reasons behind this grade imbalance and how to eliminate is direction for future work.

We found that eliminating the grade disparity in early courses will not be enough to achieve gender balance. There are other outside factors that effect a student's decision to move on in CS. Related research suggests that these could be environmental reasons or due to the lack of same-sex peer interaction in the program.

We have identified attrition early in the intro sequence and a gender-grade disparity as areas for future work. Additionally, we hope to see this study replicated at other institutions to determine if our observations reflect wider trends. It is our hope that understanding these problems in more detail will contribute to meaningful change in Computer Science.

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