Exploration of Intersectionality and Computer Science Demographics: Understanding the Historical Context of Shifts in Participation

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Although computing occupations have some of the greatest projected growth rates, there remains a deficit of graduates in these fields. The struggle to engage enough students to meet demands is particularly pronounced for groups already underrepresented in computing, specifically, individuals that self-identify as a woman, or as Black, Hispanic/Latinx, or Native American. Prior studies have begun to examine issues surrounding engagement and retention, but more understanding is needed to close the gap, and to broaden participation. In this research, we provide quantitative evidence from the Multiple-Institution Database for Investigating Engineering Longitudinal Development—a longitudinal, multi-institutional database to describe participation trends of marginalized groups in computer science. Using descriptive statistics, we present the enrollment and graduation rates for those situated at the intersection of race/ethnicity and gender between 1987 and 2018. In this work, we observed periods of significant flux for Black men and women, and White women in particular, and consistently low participation of Hispanic/Latinx and Native American men and women, and Asian women. To provide framing for the evident peaks and valleys in participation, we applied historical context analysis to describe the political, economic, and social factors and events that may have impacted each group. These results put a spotlight on populations largely overlooked in statistical work and have the potential to inform educators, administrators, and researchers about how enrollments and graduation rates have changed over time in computing fields. In addition, they offer insight into potential causes for the vicissitudes, to encourage more equal access for all students going forward.

CCS Concepts: • **Social and professional topics → Race and ethnicity**; **Women**; **History of computing**; **Computing education**;

Additional Key Words and Phrases: Women in computing, intersectionality, computing demographics, computing history, historical context analysis, race, ethnicity, gender, diversity

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1 INTRODUCTION

One major problem facing the computing workforce is the challenge to keep pace with the demand for skilled professionals. Between 2019 and 2029, computer and information technology occupations are projected to rise 11%, which is a rate faster than the average for other fields [71]. However, research indicates that the current quantity of graduates will not be able to meet the growing needs of the computing industry [16, 82]. Furthermore, there is a profound difference in the enrollment and subsequent persistence of students in technology fields when data is disaggregated across race, ethnicity, and gender [4]. Predominantly, White and Asian men have the highest levels of computing stickiness (a measure of students' persistence comparing enrollments relative to graduation rates) [112]. Studies, such as these, suggest that as a discipline we will continue to lag behind demand, particularly in terms of equal representation. This creates an urgency to learn more about those populations whose enrollments, graduation rates, and stickiness continue to be low.

In computing, there is a known underrepresentation of women, Black, Hispanic/Latinx, and Native American students and workers [14, 89, 95, 112]. Moreover, numbers are particularly low for women of color. This underrepresentation has resulted in a movement to disaggregate data to highlight their lack of presence in the field, and explicitly explore intersectional experiences in computing to give them a voice and a presence in the conversation around their participation [21, 86, 104]. Although there has been a shift in literature around this "call to action," there is still an incomplete view of their historical participation. Entities like the Computing Research Association (CRA) publish Taulbee reports; however, a disaggregation of data is only available from 2013 onward [4]. As a point of clarification, despite shifts in terminology over time, we will be using the terms "Black," "Native American," "Hispanic/Latinx," and "Asian" to refer to the populations discussed in this article, in alignment with the designations applied in the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) dataset [61].

In this work, we consider enrollment and graduation rates in computing fields, and examine trends between 1987 and 2018. Additionally, we consider the intersectionality of social identities when disaggregating the data, since prior work has demonstrated the importance of considering those situated at the intersection of race/ethnicity and gender when investigating persistence [86]. We use Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) to gather descriptive statistics of participation in computing fields, and to provide a cross-sectional look at enrollment and graduation rates of women, and especially, Black women, Hispanic/Latinx women, Native American women, and Asian women. In addition, we conduct historical context analysis to provide framing for the time periods identified in the quantitative study as having notable shifts in participation. To this end, we consider a **notable shift** as follows:

> *A change in the enrollment or graduation rates of a specific intersectional group from relatively stable value over the span of several years to one that is comparatively higher or lower the following year(s). The precise amount of fluctuation is determined by the proportional representation within the group of study as compared to the overall population.*

In the work described, our overall population is defined as all computing students across the institutions reported in MIDFIELD. The specific research questions guiding this study are:

(1) How have White, Black, Hispanic/Latinx, Native American, and Asian women's participation in computing shifted over time?
(2) What major historical events and activities describe the context of the notable shifts observed in women's participation?

We will begin by first reviewing the background work in Section 2. In Section 3, we describe the dataset that we utilized, as well as what quantitative and qualitative methods we employed. We provide the results of the quantitative analysis of MIDFIELD in Section 4, along with briefly mentioning the qualitative results. Then, in Section 5, we provide a discussion of our findings and the historical context analysis. Finally, we present the limitations to this work in Section 6, and finish in Section 7 with the conclusions and broader impacts of these findings.

2 RELATED RESEARCH

In this section, we will present an overview of existing literature related to the participation of computing students, with additional consideration for work that focuses on Black, Hispanic/Latinx, Native American, and Asian women. First, we introduce intersectionality, a concept that frames our inquiry, in Section 2.1. Then, we follow up with research that considers the enrollment and persistence of computing students in Section 2.2.

2.1 Intersectionality

Intersectionality refers to a theoretical framework for exploring the overlapping components of an individual's identities—whether political (e.g., political affiliations), social (e.g., race, gender, disability), organizational (e.g., job title), or circumstantial (e.g., student, parent) [26]. Intersectionality is a call to scholars to not ignore or undervalue the complexities associated with experiences of those that stratify more than one axis of oppression, including race, gender, class, sexual orientation, and so on [28, 31]. This framework points out that women are not a monolith and, as such, do not experience life or marginality the same [8, 23, 60]. Previously, literature has described how women of color are shaped by existing within multiple spheres of minority categorization, often facing both racism and sexism, and the importance of considering intersectional identity as more than just the sum of individual labels [29]. Intersectionality presents the opportunity and the argument for disaggregating data and evaluating, in this case, Black women, Hispanic women, Native American women, and Asian women and their complex identities rather than lose them in overgeneralized, aggregated data. Prior work by scholars interested in the nuance associated with calling attention to, investigating, and understanding the experiences of women at the intersection of race and gender have provided the precedent for continuing this line of inquiry [60, 75, 83, 86, 104, 106, 109].

In our study, we leveraged that prior work to focus on social identity, and deliberately apply an intersectional lens in selecting, presenting, and interpreting the data. Drawing on the works of Crenshaw, and others who have followed, we center these women as the focus of our work [2, 24, 28, 30, 50, 86]. While the data collection was not designed with intersectionality as the guiding framework, the research team saw the opportunity to leverage this large dataset to explore the representation trends. The use of a secondary data source (MIDFIELD) provided unique access to large student enrollment and graduation numbers and offered an opportunity to identify patterns unique to populations in computing.

2.2 Enrollment and Graduation Reporting in Computing

Publications from the United States (U.S.) Census Bureau report that the current population of computing students and professionals is not reflective of the breakdown observed in the general population of the country. For example, more than 50% of the population are women [13]; however, the number of women receiving bachelor's degrees in computer science in 2016 was only 18.7% [65]. Antithetically, when considering student persistence, it is necessary to not only consider how many students enroll but also to define retention within a program of study [95]. As such, graduation rates can serve as a measure to depict the representation of different groups upon completion of a program.

While other datasets have been created to examine trends in computing, typically they offer limited longitudinal information [4, 45]. In part, this is due to challenges in obtaining data from multiple institutions, as some may use inconsistent formatting [95]. Moreover, those organizations that do collect aggregated data rarely consider or report intersectionality, and instead statistics are presented with separate counts for gender and race/ethnicity [4, 45, 89, 113]. Although such information is indeed beneficial for computer science education research, it neglects to consider how individual groups experience computing, and the trends that may impact their participation and retention.

The top publishers pertaining to enrollment and graduation information in computing are the CRA, the National Science Foundation (NSF), and the Association for Computing Machinery (ACM) [4, 44, 68, 113]. However, the institutions that report, the sources of the data included by each, and the population size for each are distinct [68]. As a result, a direct comparison between all three may not be valid, yet each can provide useful insight into student participation.

CRA conducts a survey annually at institutions throughout the United States and Canada to describe changes in computing students' enrollment, graduation, and employment dating back to 1984 [4]. They publish the findings in the CRA Taulbee Survey. While the participation reports are quite comprehensive, and include demographic information on computer science and computer engineering students; the findings publicly available only date back to 2001, and intersectional information on undergraduates was not presented until 2013, where it is included in the 2012–2013 report. Moreover, Taulbee focuses on institutions that offer PhDs in computing fields, and they exclude for-profit institutions [4, 68, 114]. This type of reporting limits the representation of certain institutions, and in particular may result in the exclusion of minority serving schools like Historically Black Colleges and Universities (HBCUs) [68].

NSF is an independent federal agency in the U.S. that is responsible for funding a large percentage of science, technology, engineering, and mathematics (STEM)-related initiatives and research [42]. They also collect, analyze, and present data pertaining to STEM education, in conjunction with the National Center for Science and Engineering Statistics (NCSES) [44]. NCSES utilizes data from the Integrated Postsecondary Education Data System (IPEDS) survey, a national census conducted with institutions that receive federal funding. In 2015, the National Science Foundation published a report on graduation rates for degrees in computer science between 1966 and 2012 [43]. While it presented information on the gender of degree recipients, it was aggregated, and thus lacked the nuance of disaggregated data. As a follow up, NSF released another report in 2019, with NCSES, called the "Women, Minorities, and Persons with Disabilities in Science and Engineering" [65]. This report focused on the period between 2006 and 2016. While it did include statistics on women and underrepresented minorities, its focus was science and engineering, and information published specifically on computing students was limited. Much like the original NSF report, it did not present disaggregated data. An even more recent NSF report released in 2020, about science and engineering degrees, only presented data for all recipients, or by gender, with separate tables for men and women [45]. Therefore, it still neglected gender in relation to race or ethnic identification of the participants.

The Association for Computing Machinery–Non-doctoral Granting Departments in Computing (ACM-NDC) also began presenting computing demographics in 2012-2013, as a complement to Taulbee [81, 113]. The ACM-NDC survey provides annual information about non-doctoral granting four-year institutions in computing fields, including computer science, computer engineering, information systems, information technology, and software engineering [113]. While this survey does offer information about the number of graduates by gender, race, and ethnicity, demographics are not reported by intersectional group.

The limited body of work related to the enrollment and persistence of Black, Hispanic/Latinx, Native American, and Asian women suggests a necessity to disaggregate the data as well as take deliberate action to explore these populations in computing. Therefore, in this work, we attempt to resolve prior limitations by describing computing participation over a larger time span, and we do so with consideration to intersectionality.

3 METHODS

In this section, we describe the two methods leveraged for this study—quantitative inquiry into MIDFIELD and qualitative historical context analysis to provide understanding about the events or factors that occurred in society that could have impacted computing participation. We will begin by describing the MIDFIELD database, including the origin, contents, and its limitations in Section 3.1. Then, we describe the method of analysis invoked for the quantitative inquiry in Section 3.2. This is followed by a presentation of the qualitative historical context analysis, applied to define critical moments based on notable shifts observed for different groups in Section 3.3.

3.1 Database

Limitations in cross-sectional data for engineering students motivated engineering education researchers to create a longitudinal student database [18]. Through the examination of curricula and student records, they sought to create national benchmarks. In 1996, the Southeastern University and College Coalition for Engineering Education (SUCCEED) Longitudinal Database (LDB) was created through the Engineering Education Coalition (EEC) program [74], under the National Science Foundation. MIDFIELD was a result of this effort [63].

MIDFIELD is a longitudinal database with student data from 19 different institutions and consists of records for over 1.5 million undergraduates [74]. The records include demographic information (e.g., gender, ethnicity, and race) as well as, what we will refer to as, transcript data. Transcript data allows MIDFIELD users to track academic information throughout the duration of a student's education including academic major, courses taken, grades, and graduation. MIDFIELD began data collection in 1987 and continues to do so currently, adding new participating institutions annually. Due to the size of this dataset, MIDFIELD has the potential of supporting analyses of disaggregated data to provide valuable insights into populations often omitted due to small numbers [61].

Although MIDFIELD includes students majoring in various disciplines, we were only interested in computing students, and thus stratified using the Classification of Instructional Programs (CIP) coding system by which CIP2 was set to 11 for computer and information sciences. This included students in computer science (CS), computer programming (CP), information technology (IT), and information science (IS). After filtering the entire database on this CIP code, we established a reduced dataset of approximately 43,000 students from 1987–2018. However, it should be noted that not all schools reported for all years. The complete timeline for when the 19 different schools reported is shown in Figure 1.

The reporting universities and colleges were geographically dispersed throughout the U.S. and represented varying types of institutions (private, public, small, medium, and large), including Predominately White Institutions (PWIs), two HBCUs, and one Hispanic-Serving Institution (HSI). The two HBCUs stopped reporting after 2003 and 2004, which may explain one shift in demographics after this time frame (see Figure 1). There were no formal Tribal Colleges and Universities (TCUs) or Asian American Native American Pacific Islander-Serving Institutions (AANAPISIs) in this dataset.

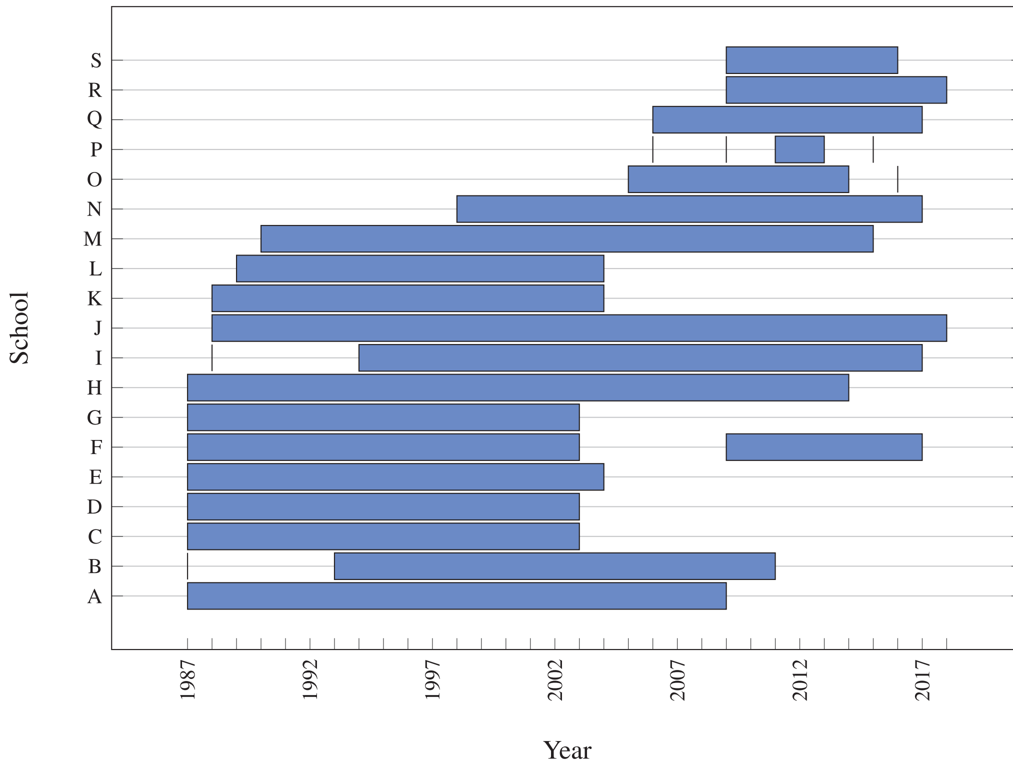

Fig. 1. Years in which schools reported data in MIDFIELD over time.

3.2 Quantitative Data Analysis

For quantitative data analysis, we used Python version 3.7.4, along with the Pandas and NumPy libraries, to calculate descriptive statistics of the intersectional populations in MIDFIELD. The purpose was to simply illustrate the rates of participation and graduation rates of each group over time. As such, all demographics were calculated annually for both enrollment and graduation as percentages of each group (e.g., Black women) across institutions, relative to the total population of students in computing that year. This type of reporting, with demographics calculated as a percent of the total, is consistent with the work of others [10, 59, 60]. No averages were calculated. While MIDFIELD includes information between 1987 and 2018, we limited the graduation analysis to a subset of 1987–2012, because we wanted to allow six years to ensure any students who may have enrolled had the average time to graduation of six years. The chosen dates are consistent with the six year window recommended by the National Center for Educational Statistics [69].

3.3 Historical Context Analysis

To try to explain the stark peaks and valleys in the quantitative analysis, we applied historical context analysis. Historical context analysis consists of a critical examination of documented past conditions to describe the political, cultural, economic, and social climate that defined critical periods of change. According to Given, **context** is defined as the "*external characteristics of the situation to be studied that are situated outside the individual, group, or even institution or community that are* *the focus of interest*" [48, p. 392]. Given argues that this method is useful, since individual behavior is influenced by the historical events that define a particular place and time. Considering the relevance of broader factors that evolve and influence populations, we use historical context analysis to describe enrollment and graduation rate fluctuations in computing. Therefore, we also consider historical events in terms of institutional funding, initiatives, organizations, or groups that could impact academic decisions. Our application follows others that similarly use historical context to provide framing of quantitative data [6, 47].

This work demonstrates, however, that there is not always a direct correlation between the date of establishment, and a surge in computing enrollments or graduations. We combine the notable shifts based on quantitative numbers for enrollments and graduations in the MIDFIELD dataset with the major shifts in culture and history for women. Specifically, we focus on women that self-identify with varying racial/ethnic groups, and examine the historical efforts and events that may have contributed to the shifts observed around those periods.

While we cannot make explicit connections between our numbers and precise events, we do provide historical context for women, and particularly for women of color. Specific events have had an impact on the culture of computing and have led to meaningful moments that could affect the motivation of students' enrollment and graduation. In addition, the creation of societies, organizations, and groups that seek to broaden participation have served to raise awareness, create a community, and to try to make computing more equitable for all. Building communities has been shown to increase feelings of inclusion, to imbue students with a sense of belonging, and to aid in retention [70, 99, 106]. Sense of belonging is a critical sub-construct of computing identity, and is considered important for students' persistence as well [99]. Also, having role models, mentors, and advisors are suggested to further contribute to the establishment of a more positive computing identity [9, 85]. Therefore, we do also consider organizations and initiatives heralded by the ACM and NSF, that served to provide opportunities and develop a community for minoritized populations.

In this work, we considered a "shift" to include an increase or decrease of an intersectional population over the span of a single year, or several years. As such, the threshold applied varied by group, but for example, Black women enrollments started at 6.6% of the population in 1987, stayed within a 1% change at 7.7% of the population in 1988, and 7.4% in 1989. However, there was a more than 3% change in the early 1990s as values rose to 10.3% in 1990, peaked at 14.3% of the total population in 1991, and still remained at 10.60% in 1992, before levels declined back to prior levels of 7.7% in 1993. Since there was a sustained period of stable enrollment, where stable is considered a variation of less than 1%, we therefore consider the period of 1990–1992 when Black women were proportionally higher to be a notable historical period. However, for populations such as Native American women, where enrollments never rose above 1% of the total students in computing, the threshold for a notable historical period was reduced, and instead was defined by periods of volatility relative to those of more stable counts.

Once a notable shift was identified, we used Google and Google Scholar to search for organizations, events, figures, and publications pertaining to major historical events of relevance for each group. Phrases such as "Black or African American women in computing in the early 1990s" or "Computing organizations for Hispanic or Latina or Latino or Latinx" were queried to identify key figures, groups, or events. In addition, since frequently there were few, if any, directly applicable results, we often expanded our search to include notable women, groups, or events pertaining to STEM disciplines. For any informal blogs or articles identified, we did further query Google Scholar for validated publications on the topic/event, or we searched the organization page directly to confirm names, years, or other information that was unsubstantiated elsewhere.

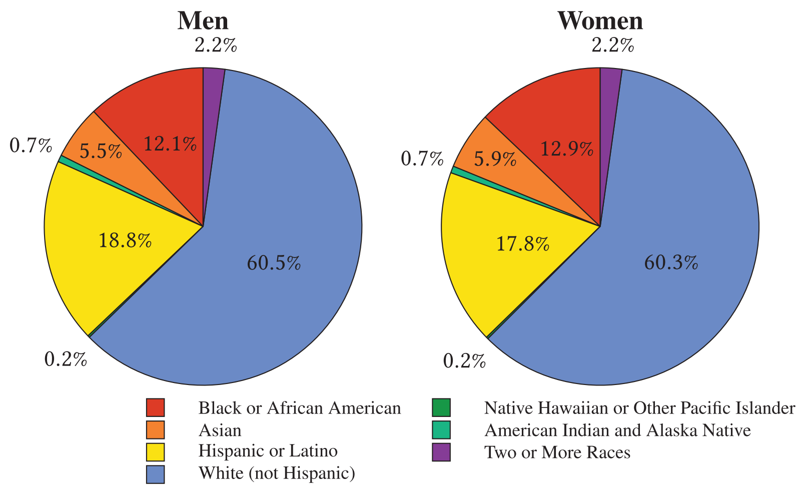

Fig. 2. Race and ethnicity demographics in the United States in 2018, based on numbers from the U.S. Census Bureau [13].

4 RESULTS

Prior literature has noted that computer science tends to struggle not only with enrollment but also with retaining students [95, 112]. Therefore, we considered undergraduate demographics over time. In this section, we first present the demographics in the U.S. to establish a comparative baseline in Section 4.1. Then, we present the findings from the quantitative results into enrollments in Section 4.2 and graduation rates in Section 4.3. Finally, we provide a brief overview of the qualitative search findings for the historical context analysis in Section 4.4.

4.1 Demographics in the U.S. in 2018

It is important to establish some of the general demographics in the U.S. for context. According to the latest U.S. Census Bureau reports, Whites represent 76.3% of the total population, and 60.1% when considering the White (not Hispanic) designation [13]. Likewise, Black/African Americans are 13.4%, American Indian and Alaska Natives are 1.3%, and Asians are 5.9% of the population. Furthermore, 18.5% of the total population are Hispanic/Latino. Women are actually 50.8% of the total demographics. Since we will consider the intersectionality of individuals in MIDFIELD, we further disaggregate these by race and gender, to demonstrate the overall demographics in the U.S. in 2018 in Figure 2. However, these statistics are not reflective of the breakdown of different populations in computing.

4.2 Enrollments

4.2.1 Total Enrollments Over Time. First, we considered the intersectionality of race/ethnicity and gender for women enrolled in computing fields, as shown in Figure 3. This was a measure of the enrollment in CS (n = 42,865) between 1987 and 2018. We will present the disaggregated data starting with the women and then following up with all students.

Although women represent 50.8% of the general population in the U.S. [13], in computing their enrollment is far lower. White women in computing tend to have the highest enrollments relative to other racial/ethnic backgrounds, yet they only accounted for 19.7% of the total computing population at its highest (in 1987), and they continued to diminish thereafter, reaching their lowest levels at 7.6% in 2018. The one notable exception to this is Black women, who had the highest enrollment of any racial/ethnic group in 1991 at 14.3% of the population. This peak was a

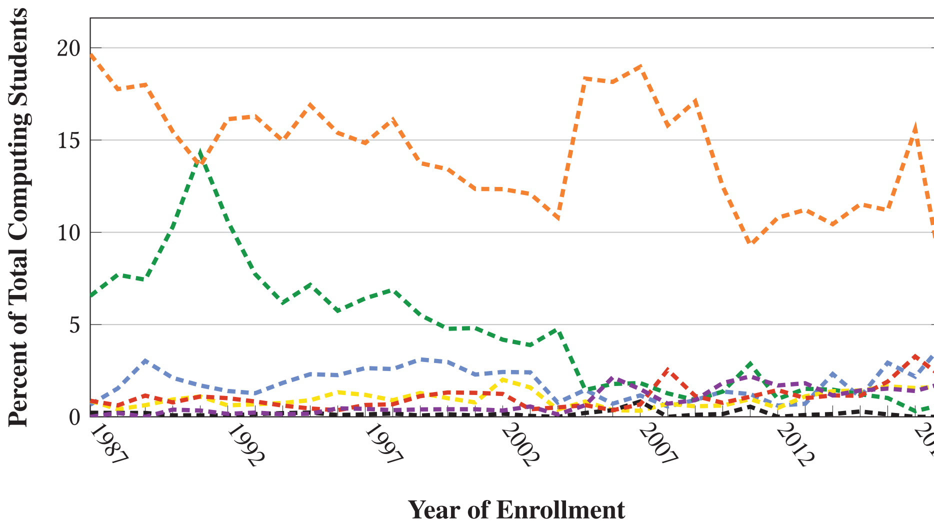

Fig. 3. Computing enrollments for women only, from 1987 to 2018.

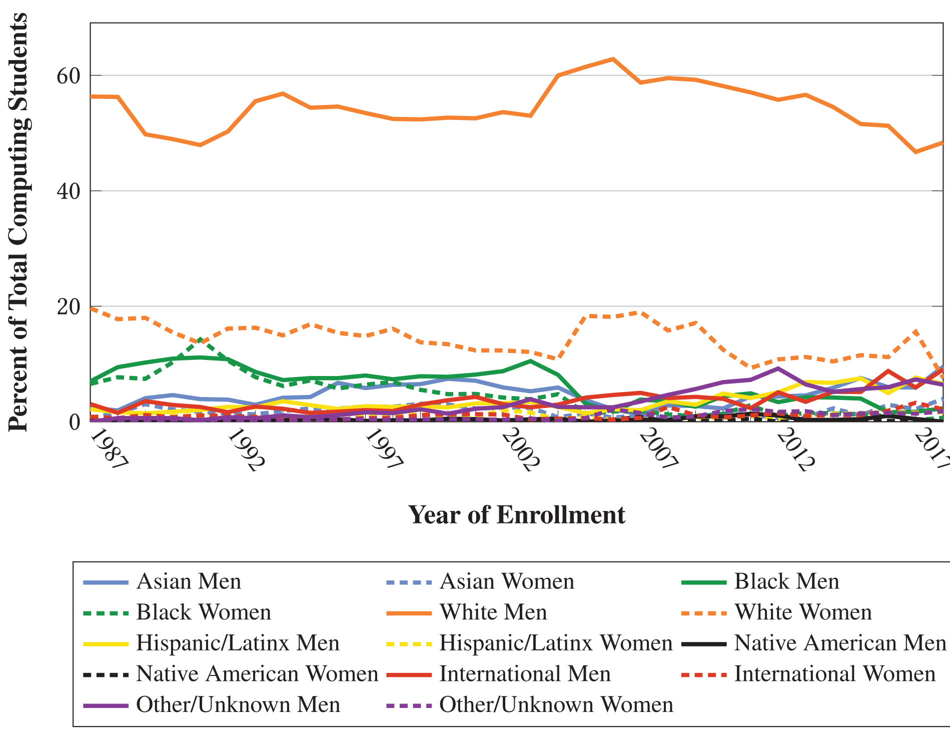

Fig. 4. Computing enrollments for all students, from 1987 to 2018.

substantial increase from the initial enrollment rates of 6.6% (in 1987). Furthermore, after achieving higher enrollments in 1991, Black women continued to diminish in the total population, reaching less than 5% in 2000, with a continued decline through the new millennia. By 2018 numbers were down to 0.7%.

Additionally, Asian, Hispanic/Latinx, and Native American women saw consistently low representation throughout the data. However, unlike Black women, whose representation in the total population declined over time, Asian women did increase, starting in 1987 at 0.7% of the population, but rising to 4.0% in 2018. Also, Native American women reach their highest representation levels at 0.8% in 2007, but otherwise rarely reach 0.5% and are even as low as 0.0% several years, including 2004, 2008, 2012, 2017, and 2018. Meanwhile, Hispanic/Latinx women are represented far less in computing than they are in the general population (as shown in Figure 2), peaking at merely 2.0% of the total computing student enrollment in 2002. Without further information, we are unable to know which groups identified as either international or other, so for the purposes of this discussion, we will not include their numbers.

Furthermore, when considering all students, as shown in Figure 4, we can visually see the stark contrast to the representation of women in computing. Consistent with prior work, White men continue to represent the largest percentage of total enrollment across all years considered. Specifically, White men's enrollment ranged between 46.7% at their lowest representation of the total computing population (in 2017) and 62.8% at their highest (in 2006). Although Asian men in this dataset do occur in computing at rates higher than observed in the general population, they still are lower than the representation in computing mentioned in other work [11, 39]. We posit this is due to the presence of an "International" category, which may also encompass students in this group. In this dataset by 2018, Asian men represented 9.5% of enrollment, and International men represented 9.1%.

We observed that Black men have higher representation than Asian men, peaking in 1991 at 11.1%. However, Black men do become less prevalent in computing over time, dropping from 8.1% of the population in 2004 to as low as 1.71% in 2017, and then ending in 2018 with 2.3% enrollment rates. In part, we anticipate the drop-off in 2004 resulted from a change in the dataset, which did lose reporting from an HBCU that year. Accordingly, this may have over-inflated the representation of Black men in the computing totals, making it appear as though they were a higher proportional representation. Antithetically, even with HBCU data, Black men are still underrepresented compared to White men (and even women). This illustrates the importance of including minority serving institutions in demographic data, to get more accurate portrayals across institutions. It also draws attention to the gross underrepresentation of Black men in computing. Often education research ignores this population due to the overrepresentation of men in this field [102].

For Native American men, the greatest enrollment percentages seen were in 2011, but this only represented 1.4% of the total population in computing. As for Hispanic men, they started at 2.9% in 1987 but rose to 7.6% of enrollments in 2017. Although they are still hugely underrepresented relative to their presence in the general population, this was at least an upward trajectory relative to the rest of the computing population.

4.3 Graduation Rates

For graduation rates, we present the data between 1987 and 2012. The rates of graduation for women in computing fields is shown in Figure 5. Overall, we observe lower levels of graduation for each group than we did for enrollment, suggesting an attrition problem. In terms of their graduation rates, White women peaked early on, with graduation rates of 23.3% in 1990. However, White women continued to decline after this year, dropping to their lowest in 2007, where they consisted of only 4.0% of the total graduations. Although the time to graduation may vary by student, this is still fairly low assuming four or five years to obtain a degree would mean a drop-off from their 12.3% enrollment in 2002 and 12.1% in 2003.

In addition, Black women peaked at 9.3% in 1995, which would be consistent with their peak enrollments four years prior in 1991. However, this too represents a dropoff between the levels

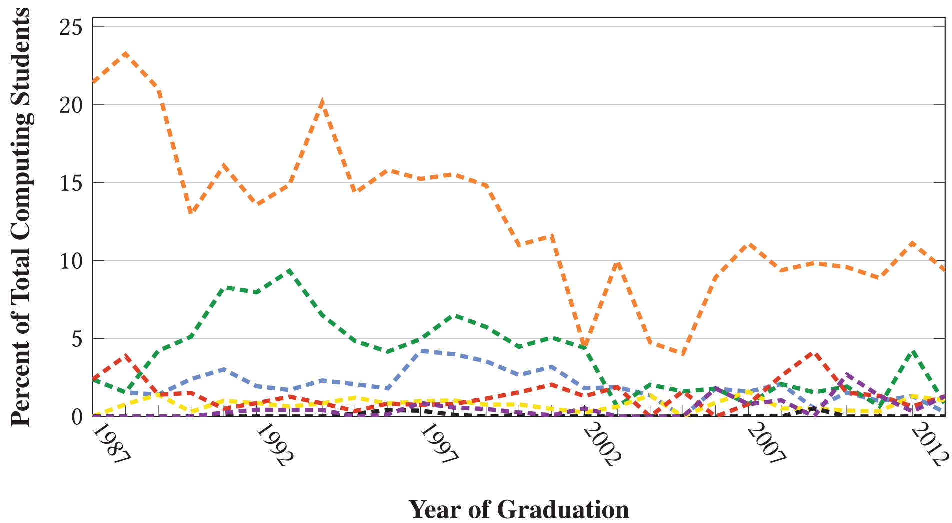

Fig. 5. Computing graduations for women only, from 1987 to 2012.

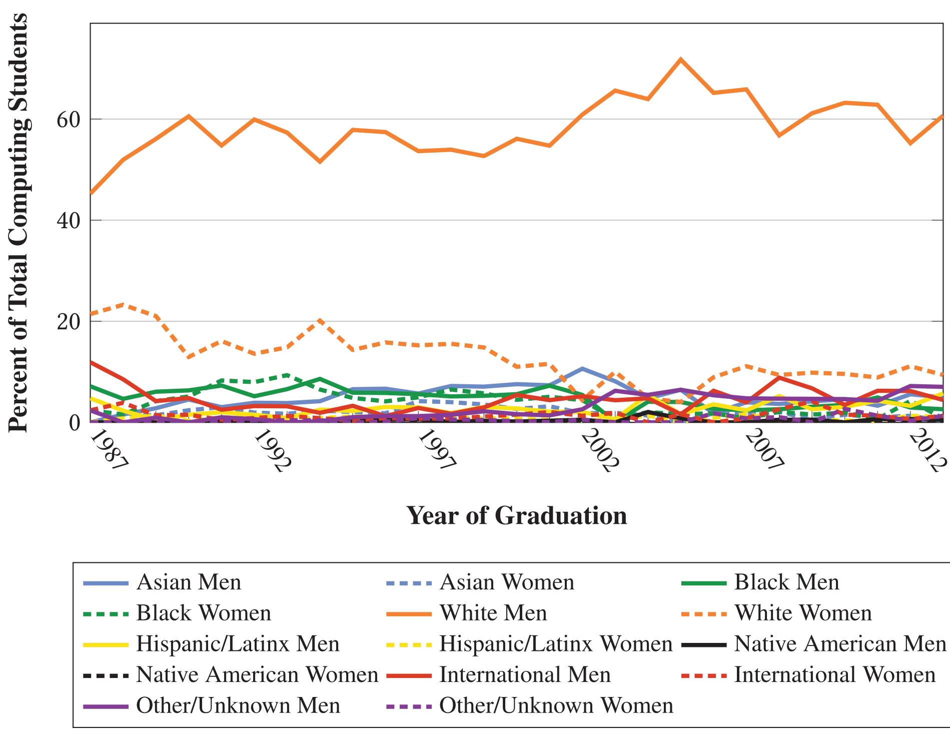

Fig. 6. Computing graduations for all students, from 1987 to 2012.

enrolled and the representation of Black women in the total computing population upon graduation. Additionally, Black women reached their lowest rates of graduation in 2005, representing only 0.6% of the total graduates. Interestingly, Asian women tended to represent a larger percentage of graduates in computing than they represented in enrollments. Asian women were at the highest between 1999 and 2000, at 4.2% and 4.0% of the total graduations, respectively. They were also at their lowest in 2007. Meanwhile, Hispanic women consistently were less than 2.0%, only reaching 1.6% at their highest (in 2009). Unfortunately, the data suggests that there were many years that Native American women had no graduates. Native American women reached their highest levels in 2011 at 0.5%.

The graduation rate trends for all students in computing fields is illustrated in Figure 6. Again, the largest demographic with regards to graduation rates was White men, which ranged between 45.2% (1989) and 71.8% in 2007. The highest graduation rate seen for non-White men was Asian men in 2004, which had a 10.6% graduation rate. However, it should be noted that these rates are proportionally higher than the percentage of Asians represented in the general population (see Figure 2). Furthermore, Black men had their highest graduation rates in 1996, peaking at 8.6%, but were quite variable otherwise. Black men were observed as dropping, and remaining, beneath 5% from 2005 onward. Meanwhile, Hispanic men saw their highest graduation rates of 5.4% (in 2006), and their lowest levels at 0.6% (in 2005). For many years Native American men had no graduates as well, in spite of those trends they did reach 2.0% in 2006.

4.4 Qualitative Results Informing Historical Context Analysis

We searched between 1987 and 2018 for events, figures, and organizations pertaining to underrepresented groups in computing. In particular, we explored literature for periods of notable shifts identified in the quantitative results. We will describe the historical context further in Section 5. However, we do want to point out that in the process of searching, we were only able to identify a small amount of information about women, and especially women of color, in computing. While this was in part due to the time span searched (1987–2018), and there were notable women in STEM, they were not computing-related. The most notable observation was the dearth of literature on minoritized women in computing and their contributions to the discipline. While there were mentions in popular works or informal blogs, there were limited historical contributions described in scholarly publications. This absence of rigorous, scholarly work focused on the contributions of women of color to computing should be investigated in future work.

5 DISCUSSION

The MIDFIELD database provided a unique opportunity to explore and amplify the status of women at the intersection of race and gender over time in computing. While this exploration largely yielded results consistent with other reports, in that White men represent the highest proportion of enrollment and graduation rates of all students in computing, it also provided a clear and often overlooked insight into the state of women over time. Although we do not explore the other attributes in the MIDFIELD dataset, future work should explore trends associated with courses taken, GPA, SAT/ACT scores, and other attributes for individual students over time.

While there may be a variety of factors that contribute to patterns of enrollment, persistence, and graduation, in Section 5.1 we describe some potential historical and cultural events and influences that may have lead to the shifts observed in the MIDFIELD dataset for women, and particularly for Black women, Hispanic/Latinx women, Native American women, and Asian women. Then, we make suggestions about how to improve the participation of women and underrepresented racial/ethnic groups in Section 5.2.

5.1 Historical Events and Cultural Shifts Impacting Participation in Computing

From a historical perspective, a number of changes may account for some of the observed trends in the MIDFIELD dataset. In this section, we will explore some of the programs, organizations, and initiatives that may have had an impact on the major positive and negative shifts we observed. All of these efforts could be identified as factors that contributed to the diversity shifts in computing enrollment. We begin in Section 5.1.1 by considering key developments for broadening participation of women in computing fields.

Since we defined intersectionality, we know that too often, research on women can be misleading with regards to engagement. Merely looking at trends of women often results in the omission of the full picture of the various trends of Black, Hispanic, and Native American women in the fields of computing. As has been demonstrated, they have their own patterns of engagement [86, 94]. Accordingly, we discuss Black women in Section 5.1.2. Then, we review Hispanic/Latinx women in Section 5.1.3. In Section 5.1.4, Native American women are addressed. Finally, we cover Asian women in Section 5.1.5.

5.1.1 Major Developments for Women in Computing Fields. In this section, we will discuss broad initiatives to engage underrepresented groups in computing, with a focus on women. For reference, we provide a broad timeline of historical events relative to enrollments of women in Appendix A. While it is not necessary to contextualize women in relation to men, we will do so to provide framing for those that may not be aware of the disparity.

Relative to the men in the MIDFIELD dataset, women tended to have lower enrollment and graduation rates overall. This is consistent with other reports and research [3]. In computer science, the number of bachelor's degrees awarded to women increased from a few hundred in 1970 to almost 14,000 in the late 1980s [88]. However, it started to decline in 1990, and then stagnated in the mid-1990s. Overall, we observe that women never rise above 20% enrollments for any racial or ethnic group. Moreover, even White women, which tend to have the highest rates for women overall, are well below the percentages for White men.

White women had their highest representation in total enrollment in 1987, a time that also included some major developments towards the inclusivity of women in computing. In 1987, Dr. Anita Borg and 12 other women in computer science started a community connected via email, called Systers, to discuss problems at work, technical issues, and to share resources [1, 3]. Although initially established for communication between women in academia, it later grew to include women from industry as well [3].

Between 1993 and 1994, there was a decline in the enrollment of both Black and White women in the MIDFIELD dataset. Accordingly, this decline could have been the motivation behind several individuals and organizations created in the 1990s to facilitate the development of a more inclusive environment. After recognizing that there was unequal representation in computing, the ACM created a committee in 1990 to broaden participation [3]. One focus was to undo policies that gave unfair advantages on the basis of race or gender; although despite intentions, few actionable decisions and measures were actually achieved [3]. However, in 1993 a new committee was established called the Committee on the Status of Women in Computing. Later, this committee was renamed to ACM Committee on Women in Computing (ACM-W). According to historical records, they tried to encourage activities like mentoring, or promotion of the accomplishments of women, to bolster the representation of women.

Then in 1994, the Grace Hopper Celebration (GHC) of Women in Computing, co-founded by Dr. Anita Borg and Dr. Telle Whitney, was created as a conference for women in technology from around the world [1, 110]. Prior studies have demonstrated that celebrations of women's contributions to a community are important for fostering a sense of community [103]. Moreover, it was reported that not only did attendees report feeling "[...] inspired by the role models they saw at the conference [...]" but more than half reported they intended to continue to communicate with other participants at such events. In addition, the Anita Borg Institute (ABI) sought to expand internationally, which it did with a 2010 Grace Hopper Celebration in India.

The creation of GHC was followed by the establishment of a not-for-profit called the Institute for Women and Technology (IWT) on the Xerox PARC campus in 1997 by Dr. Anita Borg, with the intent to improve women's participation in computing and engineering fields [1, 110]. Upon Dr. Borg's passing in 2003, Dr. Telle Whitney and the board of directors renamed this group the Anita Borg Institute [1]. In addition to supporting Systers and Grace Hopper, they also created several workshops to help women develop skills and leadership, such as "Developing and Running Effective Organizations and Institutions" [3]. In addition, they held hackathons, networking events, offered career services, and created a forum for executives in technology.

In 1997, the NSF also developed the Professional Opportunities for Women in Research and Education (POWRE) Program, with the intention of highlighting women in STEM fields [41]. In 2001, this program was combined into ADVANCE, a program established to support gender equity. Additionally, the ACM Richard Tapia Celebration of Diversity in Computing was first launched in 2001 as a symposium [7]. It was established to encourage diverse networks that would allow students, faculty, and professionals the chance to connect. Then in 2004, the NSF also chartered the National Center for Women & Information Technology (NCWIT) to improve participation of women in computing [40].

According to MIDFIELD, in 2009 Black women reached some of their lowest enrollments, dipping down to 0.9%, and the enrollments of White women went from 17.1% in 2009 down to 12.5% in 2010, and then even lower in 2011 at 9.3%. Although these declines may be the result of many things, they also may have been the impetus for some efforts we present to improve the representation of women. Girl Develop It was established by Sara Chipps and Vanessa Hurstin in 2010 to offer events like meetups and hackathons, as well as low-cost courses on computing topics [3]. Furthermore, PyLadies was founded in 2011 as an international coding and support network for women, with a focus on the Python programming language [35]. In 2012, the she++ conference was established at Stanford University by Ayna Agarwal and Ellora Israni, to encourage women to pursue computing careers [3]. Not only did this event include attendance from several major technology companies, but she++ went on to establish a fellowship and mentoring program for high school and college students [3, 91].

Additionally, in an attempt to attract girls to computing from a younger age, Black Girls Code (founded in 2011) and Girls Who Code (founded in 2012) were established [22, 56]. Black Girls Code is a group founded specifically for women of color by Kimberly Bryant, that has mentored over 14,000 girls in the United States and South Africa [56]. Meanwhile, Girls Who Code was founded by Reshma Saujani and began as 20 girls in a single state and has since expanded to roughly 10,000 girls across 42 states [22]. Both work to help girls develop their coding skills through classes, programs, and workshops, and were created to encourage girls to pursue careers in computing fields [22, 56]. These organizations serve to establish a supportive community for women, and to build "[...] the confidence they need to succeed in a traditionally male-dominated industry [...]" [22]. Also, 90% of the graduates from the Girls Who Code summer immersion program stated that they intended to select a major or minor in a computing field. Although it is too early to substantiate this by actual enrollments, it does represent a positive intent created by such programs to encourage a more diverse population to consider computing as an occupational pursuit.

5.1.2 Black Women. Minority serving institutions have demonstrated the ability to foster a sense of community and belonging amongst diverse populations and have been lauded for their contribution to diversifying STEM [73]. HBCUs in particular, have achieved the goal of improving academic outcomes for Black/African Americans [3, 76]. African American students at HBCUs are less likely than students at PWIs to report feelings of isolation, racial discrimination, or lack of social or academic integration [96]. Furthermore, HBCUs have traditionally been a large producer of African American STEM baccalaureate degree recipients. As of 2007, there were 89 four-year and 14 two-year HBCUs. In addition to these HBCUs, there are approximately 50 predominantly Black universities, which are defined as institutions in which student enrollment is more than half African American [12, 73]. In the MIDFIELD, there are two HBCUs that report, which may impact some of the enrollment and graduations numbers observed between 1987 and 2004.

Although efforts have been made to increase the participation of Blacks/African Americans in STEM fields, numbers still remain low [3]. Moreover, often graduation percentages tend to be lower than enrollments, suggesting there is an attrition problem. It is important to continue the research to investigate the contributing factors. However, as seen in our results, there are several periods of time where there have been peaks and valleys for both Black women and men. For reference, we provide a broad timeline of historical events relative to enrollments of Black women in Appendix B.

We observe two major shifts for Black enrollment rates in the MIDFIELD dataset. The first of which include spikes in the early 1990s for Black women; and for which is also a corresponding peak in graduation several years after the fact. We cannot infer direct causality from our work; however, there were a number of historical, political, cultural, and psychosocial factors that impacted the Black population. There were several movements for racial justice that occurred at universities in the late 1980s and early 1990s [3]. In 1987 and 1988, the appearance of racial fliers at the University of Wisconsin encouraged the administration to act [34]. The chancellor pledged to double minority enrollment, to increase minority faculty hiring, to require cultural orientation for new students, and to amend the university's course offering to increase courses for Blacks and Hispanics. Also, racial crimes committed at the University of Massachusetts (in 1988) resulted in 200 minority students participating in a six-day sit-in at the Africa House [3]. This peaceful protest was conducted to demand more stringent punishment for racial violence, and to request a more multi-cultural curriculum. The administration agreed to both. Furthermore, in 1989 students at Howard University led protests against the appointment of Lee Atwater (the Chairman of the Republican National Committee) to the university's board of trustees [3, 27, 64]. Based on historical reports, the students felt his views were contrary to those of minorities and demanded his resignation, which did indeed occur. Additionally, the Supreme Court made a ruling in 1992 (in the case of U.S. v. Fordice) that Mississippi needed to take more initiative to integrate their White and Black institutions [3]. Combined, these incidents (and the resulting gains) may have led to nationwide resistant capital and empowerment for Blacks/African Americans that may have encouraged greater enrollment in the early 1990s.

It is difficult to say how these events directly impacted students' choice to pursue computing. However, we do know that these shifts created an opportunity for access for Black students leading to an overall enrollment shift, and computing was a beneficiary. Given recent unrest, (the 2020 resurgence of the Black Lives Matter movement, in part due to the murder of George Floyd), there has been a call to action from the computing community to not just be a beneficiary but an active leader of change [51]. As a community, we have an opportunity to raise the profile of computing and its impact on social justice to entice a new wave of diverse computing students into the field.

Beyond the changes observed in the 1990s, we also observe that Black men and women decline around 2004 in computing. However, the decrease in enrollment around 2003–2004 may be attributed to the loss of HBCUs in the dataset. MIDFIELD schools do include a large percentage of Black graduates [61], and as previously mentioned, two HBCUs stopped reporting around this time. Therefore, although there are several schools in the dataset that historically are responsible for producing high levels of Black graduates [61], these two could account for this trend. This is something to consider not only with MIDFIELD but also in other work with longitudinal data, that inclusion of different types of MSIs could lead to meaningful data on distinct populations.

Accordingly, we want to emphasize that researchers should consider the impact of sampling, and greater inclusion for more accurate reporting.

Without the HBCUs, as mentioned previously, enrollment for Black women reaches its lowest levels in 2009, and is also only at 1.0% of the total computing population in 2012. Several groups were created around this time to promote Black/African American success, which may lead to long term enrollments and retention, although we are unable to predict based on our present data. Black Women in Computing (BWiC) was established in 2011 by Dr. Danielle Cummings, along with the ABI, to encourage the participation of Black women and other minorities in the field [53]. Then in 2013, an NSF grant was awarded to establish the Institute for African-American Mentoring in Computing Sciences (iAAMCS) [38]. Although created locally, it became a national resource designed to improve the participation of Black/African American students in computing by creating programs and providing mentoring, training, research grants, and peer mentoring [37]. In 2016, to further their mission, the National Society for Blacks in Computing (NSBC) conference was created under the support of iAAMCS. These efforts have had a major impact on Black enrollment in computer science PhD programs. Furthermore, the inaugural BWiC conference (BlackComputeHER) was held at Howard University for students, faculty, and professionals in 2017 [15]. This initial gathering served, and continues to serve, to facilitate discussion surrounding gender and race in technology fields, and to provide resources and support for Black women during their education and careers.

5.1.3 Hispanic/Latinx Women. Hispanic populations in the U.S. have grown rapidly over the past several decades. This group grew by roughly 60% in the 1990s [3], although we do not see an increase in computing enrollment until the early 2000s. In particular, we note enrollments of Hispanic women peak at 2.0% in 2002. However, leading up to this time frame, there were several notable shifts in culture, and historical events that may have led to this rise in the Hispanic population in STEM fields, and especially in computing. We provide a broad timeline of historical events relative to enrollments of Hispanic/Latinx women for reference in Appendix C.

In 1986, the Hispanic Association of College and Universities (HACU) was established by academic and business leaders to promote higher education for Hispanics [3]. Then, as part of the Higher Education Act in 1992, HACU wrote language included in the bill passed by Congress to create Hispanic-Serving Institutions. HSIs have demonstrated an important role in contributing to improving both enrollment and graduation rates in STEM fields [73]. At present, it is reported that although HSIs represent less than 6% of post-secondary institutions in the U.S., approximately half of the Hispanic/Latinx students that attend college are enrolled in HSIs [95, 111].

Unlike HBCUs, which are historically defined expressly to provide access to a particular minority, HSIs are enrollment-based [73]. Accordingly, this designation could be awarded to universities in which the total student population contained a minimum of 25% Hispanics. Moreover, this ruling mandated that HSIs that had a minimum of 50 low-income students enrolled, were able to apply for Title III funding. However, as a result, the curricula for HSIs are less defined than HBCUs, namely, the absence of education tailored to the ethnic background of Hispanics.

In addition, there were several noteworthy events for Hispanic professionals in computing. Dr. Ellen Ochoa worked to develop optical and computing hardware systems that were used by NASA [77, 90]. In 1993, she was the first Latina astronaut to go into space, aboard the space shuttle Discovery [77]. There were also several professional societies created to foster a sense of community, such as Latinos in Science and Engineering (MAES) and Society of Hispanic Professional Engineers (SHPE) [3]. In 1996, The Hispanic Technology and Telecommunications Partnership (HTTP) was established to represent the Latino population in policies pertaining to telecommunication and technology [80]. TechLatino was created in 1997 as a “technology-focused professional organization" that offers seminars, workshops, research, and policy analysis for professionals, students, and businesses [72]. Additionally, the Computing Alliance of Hispanic-serving Institutions (CAHSI) was founded in 2006 under an NSF initiative, to ameliorate the representation of Hispanics enrolled in universities and present in industry [20]. Also, in 2006, a group of Latinas gathered at Grace Hopper Celebration and formed Latinas in Computing, a group that is involved in different workshops, conferences, and professional groups to form a network of Hispanic women/Latinas [54]. Furthermore, in partnership with HTTP, the Latino Tech Summit was established in 2016 to create a community of Hispanics/Latinx individuals and companies that work in technology [98].

5.1.4 Native American Women. More than a third of Native American college or university enrollees are older than 30, roughly two thirds are women, and typically these students are financially independent [3, 97]. Although an increasing number of TCUs offer bachelor's and graduate degrees, several only offer certifications or two-year degrees [107, 108]. Thus, although Native Americans are about 1.3% of the total population, they represent roughly 0.5% of engineering enrollment [13, 57]. Moreover, Native Americans are typically less likely to pursue a STEM graduate degree, and advanced degrees are usually in the fields of education, business, history, or social science [32]. In MIDFIELD, we observe low levels of enrollments and graduation rates in computing for both men and women. We provide a broad timeline of historical events relative to enrollments of Native American women in Appendix D.

Several programs and initiatives were established for Native Americans over time. In the late 1960s, the first tribal colleges were established to encourage higher education without requiring an assimilation into White culture [3, 46]. Also, in 1994 they were granted land status by Congress, which ensured ongoing funding. Presently, there are 37 fully accredited TCUs, although less than one fifth of all Native Americans that are enrolled in college are enrolled in a TCU. However, enrollments more than doubled at TCUs between 1990 and 2005. In 2000, the NSF established the Tribal Colleges and Universities Program (TCUP) to support technology upgrades and the purchase of equipment, and to promote outreach [3]. Furthermore, the South Dakota School of Mines and Technology developed a program in 2008 called Tiospaye, to support the enrollment and retention of Native American students [57]. As part of this program, not only is financial support given but also emotional support in the form of counseling, and professional support in the form of advising, networking, and mentoring. In MIDFIELD, although there are no formal TCUs, we do have one school that has a Tiospaye program, and this university reported demographics for 20 years of the MIDFIELD data. While these endeavors likely influence the participation of Native Americans in higher education, they have done little to influence computing enrollment. Native American women and men are woefully underrepresented with little to no support of their engagement in computing.

5.1.5 Asian Women. Asians are often reported as being present in STEM fields at a higher proportion than their representation in the general population. As such, Asians are often neglected in computing research and funding initiatives [17, 62, 100]. Yet, when data is further disaggregated on the basis of intersectionality Asian women have far lower levels of representation in computing than Asian men in the computing workforce and should therefore be considered independently [25]. Moreover, although certain Asian nationalities such as Indian, Chinese, and Korean are more common in computing, others such as the Hmong and the Vietnamese are still underrepresented [3]. In MIDFIELD, we do not observe Asians' enrollments ever reaching as high as their representation in the general population. Therefore, exploring the experiences and perception of Asian women can provide insight to fill the gaps. In the MIDFIELD dataset, Asians experience a decline between 2003 and 2004, but then continue to climb, and reach their highest enrollments in 2018. While no singular event or events surround these years, several notable historical occurrences did occur between 1987 and 2018 for the Asian computing community. We provide a broad timeline of historical events relative to enrollments of Asian women for reference in Appendix E.

Qiheng Hu is a computer scientist, whose work on the National Computing and Networking Facility of China (NCFC) project and talks with NSF are attributed to the launch of the internet in China [66, 105]. In 1994, a TCP/IP connection was set up to connect China to the World Wide Web [66]. Madam Hu continued to develop an online presence in the country, and co-founded the Internet Society of China (ISC) in 2001 [92].

In 2007, AANAPISIs were established as another enrollment-based MSI [73]. In particular, this designation was awarded to schools where at least 10% of the population were Asian Americans or Pacific Islanders, and where half of the students were considered low-income based on their participation in the Federal Pell Grant [67, 73, 78, 79]. By 2012, it was reported that 153 institutions were eligible for this designation, but only 78 institutions officially filed to receive this title [79]. In addition, the Society of Asian Scientists and Engineers (SASE), was also established in 2007 to support Asian professionals in science and engineering fields and to encourage support in local communities [68]. Additionally, the China Computer Federation (CCF) is a professional computing group that has partnerships with ACM and IEEE [19]. However, this organization is specific for China, and the official language used for journals and conferences is Chinese, which limits its extendability to other Asian populations. When trying to find a computing specific group or organization that did encompass a broader Asian population, we were unable to find any, which is something that should be considered in the future.

5.2 Working to Broaden Participation

Overall, the cultural shifts throughout history have led to many attempts to broaden participation, including the establishment of organizations and groups to help build up communities for women in computing. However, we must acknowledge that each student is unique, and no single strategy can be employed to encourage the persistence of all underrepresented groups. Nonetheless, it is important to consider the differences in instructional styles and training that can foster heightened interest and support. Students that come from cultural backgrounds valuing collectivism over individualism may find themselves preferring peer coding or group projects to individual assignments [93]. Furthermore, supportive peer networks have been shown to be critical for recruiting African American and Latino students in high schools into computing classes [49]. We suggest that colleges and universities should review their own curricula for potential areas of improvement, and could perhaps offer increased mentoring opportunities and peer support via the addition of discussion groups or teaching assistants to provide hands on activities for more theoretical concepts.

More creative approaches, and especially those that highlight culturally relevant pedagogy, may serve to increase interest and to facilitate learning of topics students may otherwise find challenging. One such example was an initiative created at Spelman College, a private historically Black liberal arts college for women, in which DJing tasks were used to enhance learning of data structures [55]. Black music (which the author defined as "any genre of music created by people from the African Diaspora, such as Hip Hop, R&B, Jazz, Soul, Blues, Gospel, etc.") was used to teach major concepts like classes, arrays, linked lists, and inheritance; physical instruments were also modeled using algorithms. Reactions included comments like "I was able to incorporate an important part of Black history which I think is essential to making technology accessible to all" and "It has helped put the new code into a real life perspective." While this course was established with a specific target demographic of Black women, this outside the box way of making challenging concepts approachable is a notion more universities should consider.

Furthermore, we cannot deny the impact that government-led or funded initiatives have had on moving the needle. The literal buy-in from the National Science Foundation through funding mechanisms has established many of the programs discussed above, that have expanded access and support for Black and brown people in computing. Likewise, the invisible labor of those from the least represented groups, be it women, Blacks, Hispanics/Latinxs, Native Americans, or Asians in creating their own communities, organizations, and support structures is commendable and arguably, invaluable to professional identity development and the persistence of minority engineering and computer science students [33, 84, 87, 101]. Despite the slow movement, there is still opportunity to invest, expand, and grow the profession for the better through broadening participation.

6 LIMITATIONS

While these findings demonstrate some interesting trends in enrollments and graduation rates in computing fields, there are several limitations to this work. First, the correlation presented is merely speculative and this work is not a comprehensive literature review. Furthermore, the dataset itself is subject to vicissitudes in representation of different schools. As mentioned previously, although MIDFIELD represents one of the largest longitudinal datasets, especially for intersectional data, not all universities reported each year.

Furthermore, all ethnic/racial data collected is reported by universities based on students' self-identification and over the years, the categorizations have changed, at times creating ambiguity. Furthermore, including categories such as International and Asian may have led to some confusion, resulting in participants being uncertain which to choose. This could explain, in part, why the numbers we observe for Asian students is lower than the rates reported elsewhere, particularly for Asian men [4]. Moreover, data was collected solely as a gender binary, and we acknowledge that this practice is exclusionary and should be updated to be more inclusive.

As mentioned, NSF, CRA, and ACM also publish reports on computing demographics [4, 44, 81]. However, the decision to include certain majors, or to exclude for-profit institutions can impact the findings in the population, and none of these reports include long term intersectional information. As such, direct comparison to MIDFIELD was infeasible, so we were unable to validate the results observed in our dataset with other sources of participation data.

7 CONCLUSION

Going forward, it is important for researchers to continue to examine what contributes to the enrollment and graduation rates of computing students. Despite initiatives to remediate enrollment and persistence of underrepresented groups in computing, women in computing have not seen substantial increases. Furthermore, considering the intersectionality of gender and race or ethnicity, we observe that White women, Black women and men, Hispanic/Latinx women and men, Native American women and men, and Asian women are particularly underrepresented. As such, it is important to further their unique pathways to computing, and the factors influencing persistence of these populations, not as an aggregate, but instead on their own terms. Work that explores intersectional experiences could aid in finding new ways to engage and maintain these groups in computing fields. The analysis presented is intended to encourage educators and administrators to further investigate these intersectional experiences, so that they can provide more targeted support for students with equity in mind and evaluate practices that may limit the participation of women and racial/ethnic minorities.

One potential option is to try to engage women re-entering academia at non-traditional time points. Research suggests that often women leave school for financial reasons or to take care of family [5, 36, 58]. Recruiting women returning to education, or looking to upskill or reskill, could prove a great potential source of untapped talent to reduce the underrepresentation of women in computing. Moreover, we recommend additional research into switching behavior, in terms of what encourages women from other majors to enroll and persist in computing. Understanding what motivates minoritized groups to succeed in computing, despite academic challenges and a lack of same-race and same-gender peers and faculty is critical towards improving their retention and tenacity in the face of obstacles.

Prior literature has demonstrated the value of peer support and mentoring, and universities should consider inclusion or expansion of such programs in computing. In particular, recognition has been shown to play a critical role both in engagement and retention, particularly for women and women of color, who may struggle to combat stereotypes and classroom power dynamics [52]. To further understand what can engage different populations and to encourage their persistence, future research should consider conducting more qualitative analysis about what methods or programs are most effective at providing encouragement for minoritized groups, and how recognition can further bolster identity. To this end, we also suggest that more literature formally celebrate women in computing—since finding positive role models, and highlighting their achievements could prove critical in encouraging others.

Our results also demonstrate the importance of including a wide range of universities when examining different populations in computing. Datasets should be established with reports from HBCUs, HSIs, TCUs, and AANAPISIs to gain a clear picture of the landscape. Furthermore, data collection and analysis should seek to offer intersectional breakdowns to provide greater insight about the numbers of each group, as well as their distinctive experiences. Only through enhanced understanding can we hope to broaden participation, and to make the field more equitable for all students.

APPENDICES

A TIMELINE FOR WOMEN RELATIVE TO ENROLLMENTS

We consider key historical events important for women in STEM, to provide context, in Figure 7. It should be noted that the scale presented is relative to the percentage of total computing students, which includes both males and females in computing across all institutions that reported in MIDFIELD.

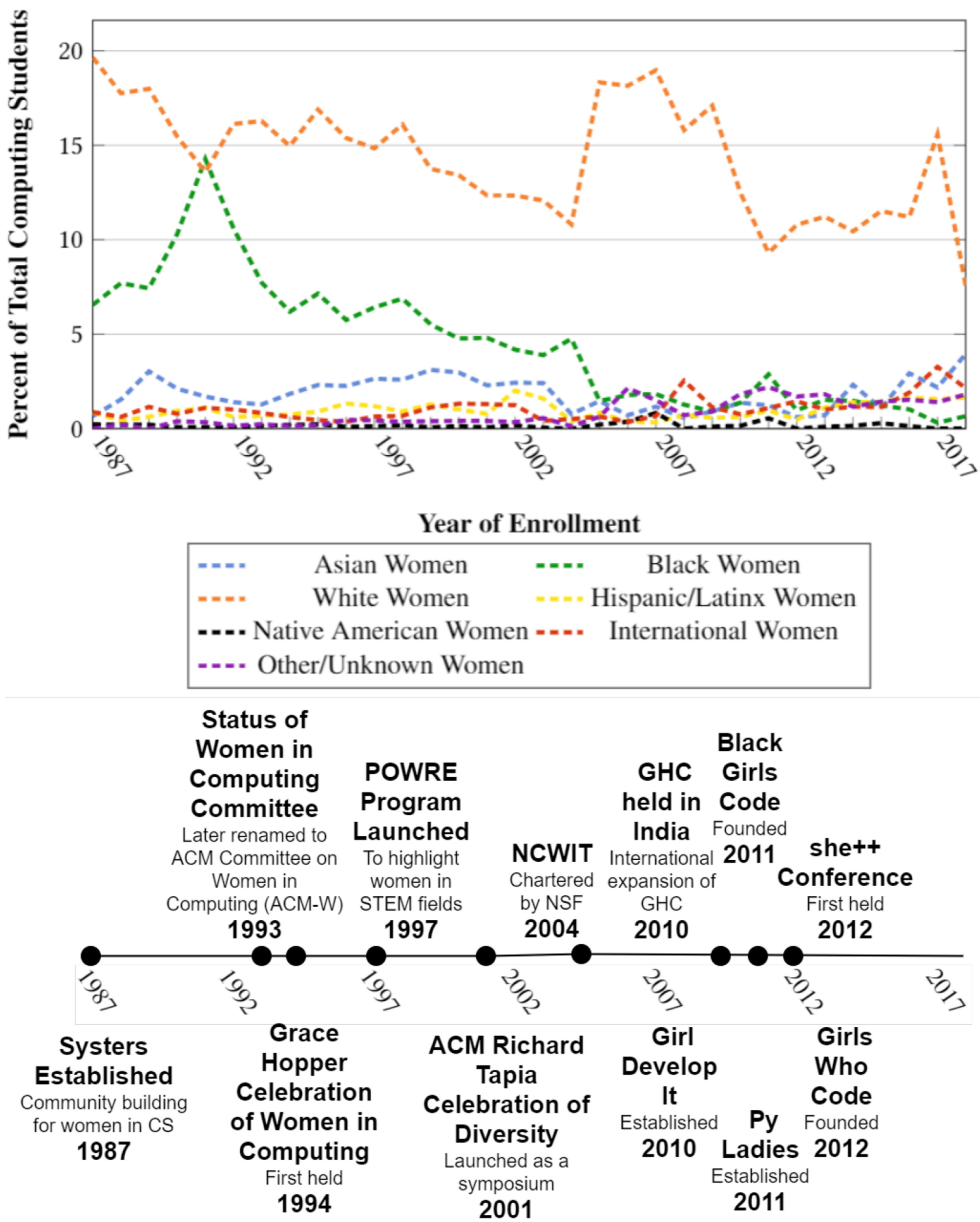

Fig. 7. Timeline for major historical events for women, relative to enrollments between 1987 and 2018.

B TIMELINE FOR BLACK WOMEN RELATIVE TO ENROLLMENTS

We consider key historical events important for Black women, to provide context, in Figure 8. It should be noted that the scale presented is relative to the percentage of total computing students, which includes both males and females in computing across all institutions that reported in MIDFIELD.

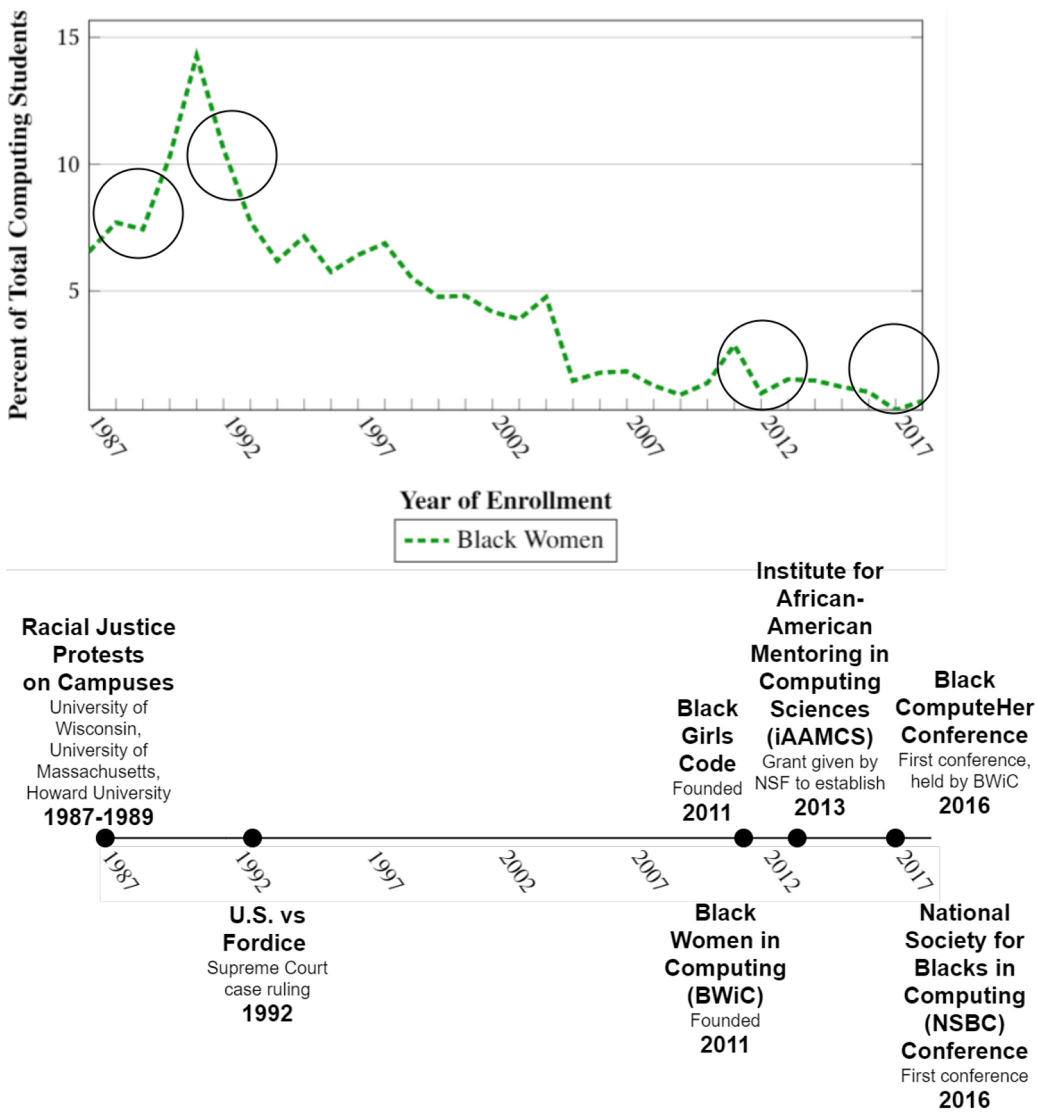

Fig. 8. Timeline for major historical events for Black women, relative to enrollments between 1987 and 2018.

C TIMELINE FOR HISPANIC/LATINX WOMEN RELATIVE TO ENROLLMENTS

We consider key historical events important for Hispanic/Latinx women in STEM, to provide context, in Figure 9. It should be noted that the scale presented is relative to the percentage of total computing students, which includes both males and females in computing across all institutions that reported in MIDFIELD.

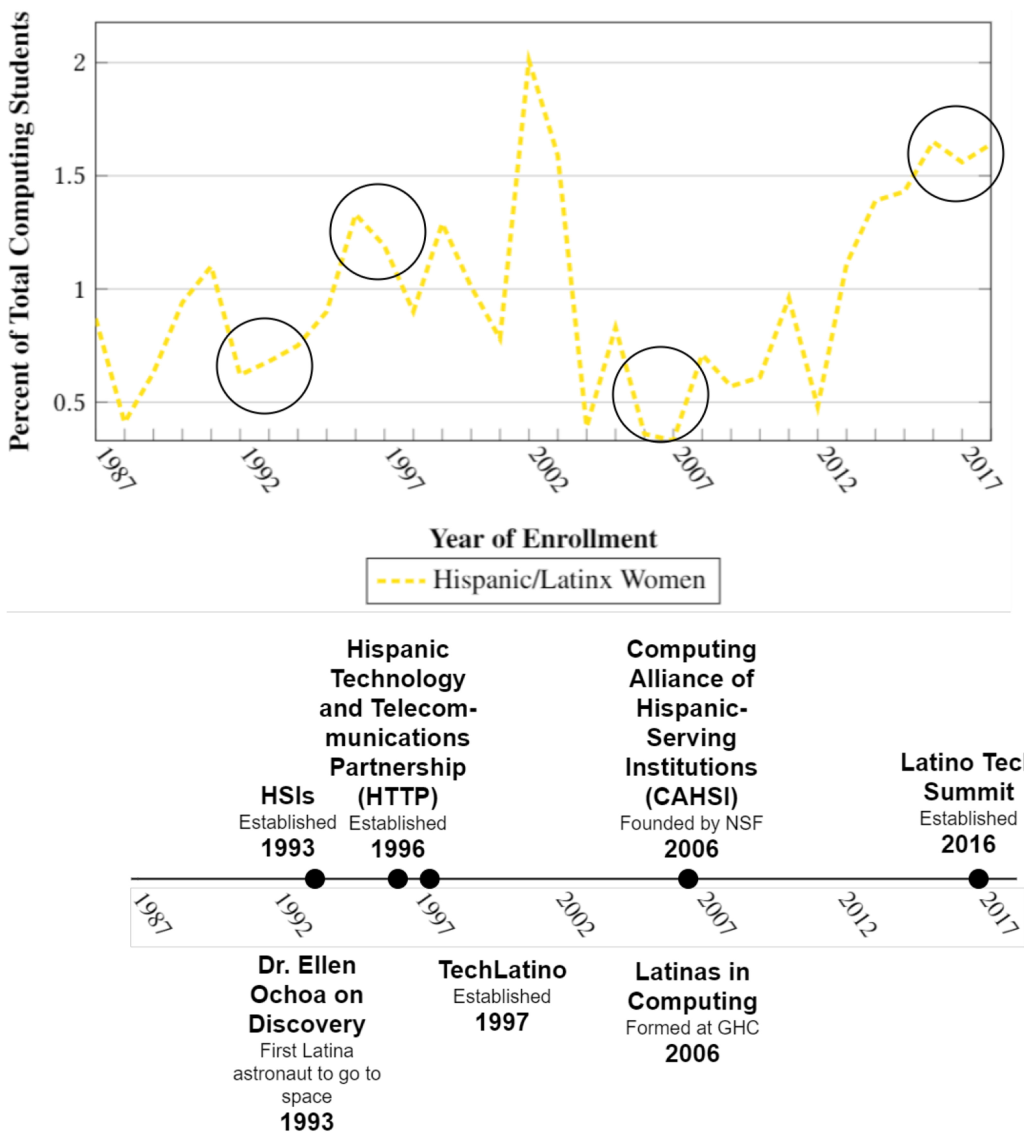

Fig. 9. Timeline for major historical events for Hispanic/Latinx women, relative to enrollments between 1987 and 2018.

D TIMELINE FOR NATIVE AMERICAN WOMEN RELATIVE TO ENROLLMENTS

We consider key historical events important for Native American women, to provide context, in Figure 10. It should be noted that the scale presented is relative to the percentage of total computing students, which includes both males and females in computing across all institutions that reported in MIDFIELD.

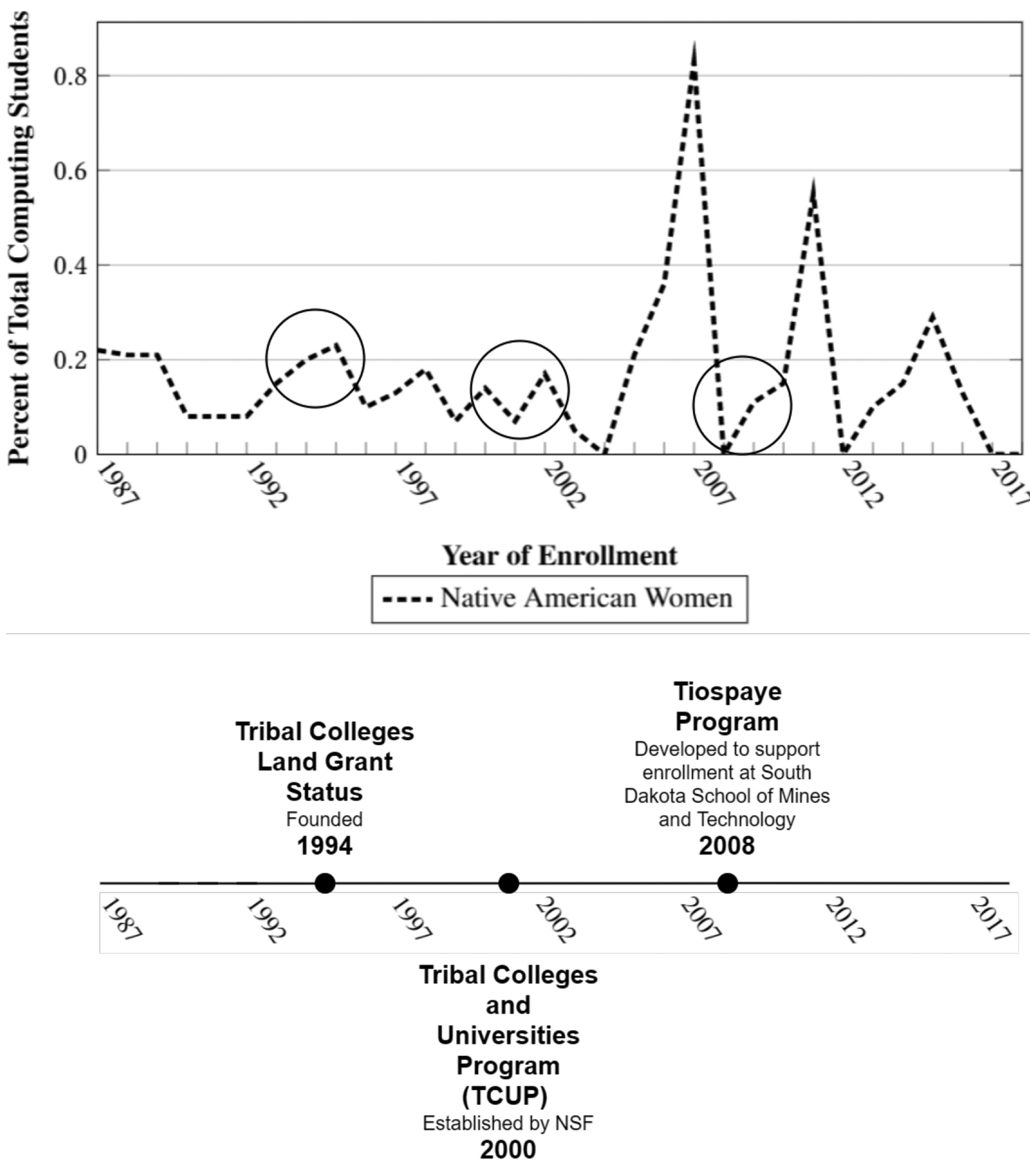

Fig. 10. Timeline for major historical events for Native American women, relative to enrollments between 1987 and 2018.

E TIMELINE FOR ASIAN WOMEN RELATIVE TO ENROLLMENTS

We consider key historical events important for Asian women, to provide context, in Figure 11. It should be noted that the scale presented is relative to the percentage of total computing students, which includes both males and females in computing across all institutions that reported in MIDFIELD.

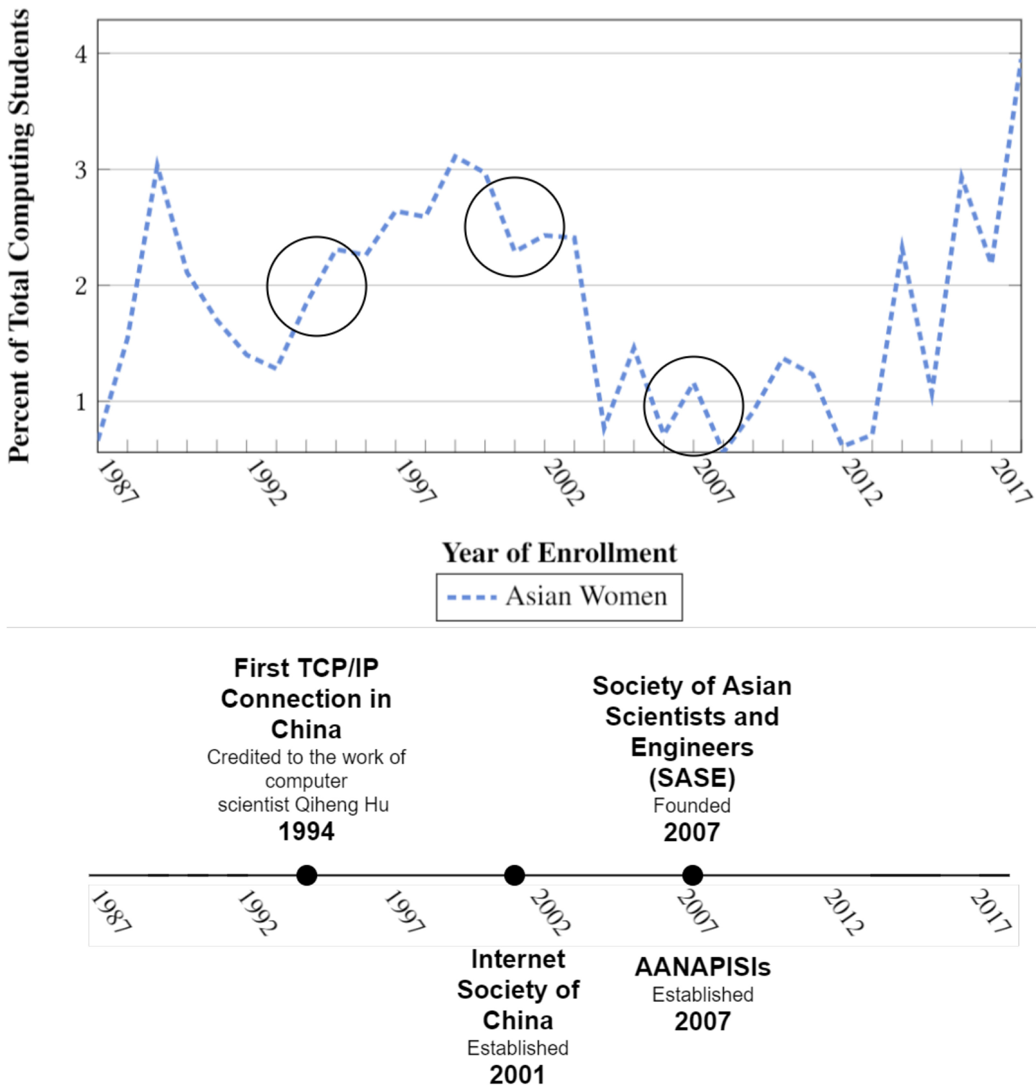

Fig. 11. Timeline for major historical events for Asian women, relative to enrollments between 1987 and 2018.

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