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Advancing Gender Equity in Undergraduate Computer Science (CS) Education

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Abstract

This paper aims to investigate the lack of progress made at the national level in the United States for addressing the long-studied, well-documented issue of women's underrepresentation in undergraduate computer science (CS) education. While not a new problem, the negative implications of this issue continually expand with the emergence of novel technological advancements and challenges. Technological innovation relies on a contribution of diverse perspectives, experiences, and mindsets, making gender diversity an important component of technological progress. By analyzing the factors that limit women's participation in undergraduate CS education and examining the success stories of Carnegie Mellon University and Harvey Mudd College, five core strategies for increasing women's participation in CS education emerge. Further, this research reveals the barriers to adoption of these strategies faced by academic institutions that have constrained their efforts to reduce the gender gap more broadly. Finally, this paper provides actionable recommendations for three primary stakeholder groups—academia, industry, and government—to support the advancement of gender equity in undergraduate CS education.

Acknowledgments

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To all those working to increase diversity, equity, and inclusion in CS, thank you for all that you do to make CS more accessible and welcoming to everyone, especially those who are currently underrepresented or marginalized in the field.

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1 Introduction

According to data from the National Center for Education Statistics (NCES), of the 97,047 bachelor's degrees in computer and information sciences conferred in the U.S. in 2020, only 21% of those graduates were women [1, Table 322.50]. The U.S. Bureau of Labor Statistics shows that women accounted for 26.2% of computer and mathematical occupations last year and only 19.7% of all software developers [2, Table 11]. Though notably low, these figures are not shocking. Gender disparities in computer science (CS) are a well-known and enduring problem, investigated in numerous studies, such as [3-12] to list a few, since the early 1990s. While not a new phenomenon, the negative implications of this issue continually expand with the emergence of new technological advancements and challenges. A diversity of perspectives, experiences, and mindsets is critical to technological innovation, of which gender diversity is an important part.

A technology is only as effective as its creators are ethical, intentional, and representative of the constituency that technology is meant to serve. The demographics of the CS student body and workforce matter because they shape the impact of developing technologies on diverse populations of users. Instances of algorithmic bias—exhibited by computer programs like the automated resume reviewer developed by Amazon in 2014 [13], which displayed preferential treatment toward male candidates over female candidates for technical roles by penalizing applications that contained the word "women's" or name of a women's college—provide evidence for this. Research from Columbia University on the causes of algorithmic bias shows that, while the level of bias in a programmer's code does not vary by demographic characteristics such as gender or race, "prediction errors are correlated within demographic groups, particularly gender" [14]. This means that any homogenous group of developers (e.g., one that is predominately male) is more prone to algorithmic bias than a heterogenous group. Increasing demographic variation in the CS workforce diversifies the identities and interests represented amongst technology creators, increasing the ability of those creators to confront and mitigate each other's biases. Thus, the more diverse the group of technology creators, the less potential there is for unchecked biases to negatively impact particular user groups.

While the technology industry has developed a focus on techniques for increasing fairness in algorithmic design and training (e.g., Microsoft's Fairlearn [15] or IBM's Artificial Intelligence (AI) Fairness 360 toolkit [16]), these efforts are limited by the fact that the perspectives of those most likely to be affected by algorithmic bias—including women and racial and ethnic minorities—are underrepresented in CS education and employment [17]. The lack of workforce diversity in CS influences the way computing systems are designed and implemented, consequently affecting the potential of those systems to negatively impact users and other stakeholders. This homogeneity poses particular challenges for subfields of CS such as machine learning, AI, and data privacy where, in the absence of comprehensive policy, computer scientists must be able to contemplate and evaluate the societal impact of their technical decisions across a range of different identities and interests. Thus, reducing gender disparities in CS fosters a diversity of perspectives needed to catalyze ethical, impactful, and relevant technological innovation.

This analysis focuses on gender inequities in undergraduate CS education, measured by the longstanding disparities in gender representation. It is important to emphasize that there are additional and compounding inequities pertaining to race, ethnicity, socioeconomic class, and disability that deserve deeper exploration than is provided here. Additionally, due to the binary nature of the data available on gender representation in CS, this analysis draws comparisons between only two gender groups: women and men. This is not meant to discount the identities of nonbinary individuals studying and working in CS; more research and new metrics are needed to understand their representation and experiences in the field.

This paper aims to investigate the lack of progress made at the national level in addressing the widely acknowledged and well-researched issue of women's underrepresentation in undergraduate CS education. The hope is that better understanding the constraints to and solutions for increasing women's representation will increase the sense of urgency for addressing issues of equity in CS education more broadly. The goal is to lay groundwork for future efforts to adapt and advance to meet the needs of further marginalized identities.

Though representation in undergraduate CS education is only one piece of the problem, colleges and universities are significant—and, in some cases, sole—sources of training for many entering the CS workforce. The past 20 years of research show that the underrepresentation of women in CS education is neither an impossible problem nor an individual one. The gender gap is a systemic problem that some academic institutions, such as Carnegie Mellon University (CMU) [8, 18] and Harvey Mudd College (HMC) [10], have ameliorated by restructuring their CS curriculum and culture with an emphasis on flexibility, interdisciplinary thinking, and practical applications to real-world problems. These schools worked to instill female students with a sense of belonging while counteracting harmful gender stereotypes that inhibit students' confidence in their knowledge and abilities. Through these changes, both schools increased their number of undergraduate CS female degree earners by upwards of 30% over a period of five years or less [8, 11].

Even with these successful examples for gaining and retaining female students in CS, representation of women in computer science at the national level remains less than half of that found at CMU and HMC. By synthesizing and analyzing the research on structural approaches to closing the gender gap in CS, such as those employed by HMC and CMU, this paper aims to:

1. Outline core strategies for collegiate CS reform.
2. Identify barriers to adoption.
3. Recommend actions for academic, industry, and government stakeholders to advance these strategies and increase gender equity in CS education.

2 Background

The key to understanding gender inequities in CS education lies in their context. What role do women play in computing today? Have they always played that role? How have the culture and characterization of CS shifted over time, and how have those changes affected women in the field? Tracing the problem back to its origins helps to identify the factors that limit women's participation in computing and evaluate effective mitigations.

2.1 Brief History of Demographic Trends in Computing

While the lack of gender diversity in CS education is a longstanding problem, overall, women experienced greater representation in the field's early decades than they do today. The percentage of female CS undergraduates in the 1980s nearly doubled current figures, reaching a peak of 37% in 1984 [19, Table 274]. All the while, the rates at which women pursued postsecondary education were climbing. By the late 1970s, women were equally as likely as men to enroll in college [20], and since 1991, they have accounted for over 50% of undergraduate degree earners [21, Table 322.2]. It seems odd, during a period of progress for women's educational achievement, that computer science should see such a regression. That said, at the same time, the field of computer science was experiencing its own period of broad-scale change.

In 1964, Dartmouth professors John G. Kemeny and Thomas E. Kurtz developed the Beginner's All-Purpose Symbolic Instruction Code (BASIC), a programming language designed with novice computer users in mind [22]. BASIC paved the way for the 1975 release of the MITS Altair 8800—the machine that coined the term "personal computer" [23]. The next decade saw rapid expansion of the U.S. personal computing market, with the introduction of products like the Commodore 64 and the first Apple Macintosh into more and more American homes. By the advent of the World Wide Web in 1989 [24], computing had entered mainstream American culture, giving rise to the hacker stereotype embodied by Matthew Broderick's character in the 1983 classic *WarGames* and the idolization of "tech geniuses" like Bill Gates and Steve Jobs. All these changes culminated in a recharacterization of computer science from menial and secretarial work, as it was perceived in the days of punch cards and batch processing [25], to the innovative and creative work of the future.

Understanding American society's traditional gendering of work roles—relegating labor deemed unskilled to women while reserving more prestigious, cerebral professions for men—sheds some light on the coincidence of women's declining representation in CS education with the start of the dot-com boom in 1995. From 1995 to 2005, the U.S. saw an increase of more than 121% in the number of undergraduate CS degrees conferred [19, 26]. Over the same period, the proportion of female CS degree earners decreased by 7%, hitting the lowest rate in decades (with women only accounting for 17% of CS degree earners) in 2010 [27]. Figure 2-1 demonstrates that, compared to the steep upward trend in the overall number of CS degrees earned since 2010, the trend line for degrees earned by women has remained relatively flat. As shown in Figure 2-2, women's representation in the field hovered between 17% and 18% for years until 2018, and, even now at 21%, remains lower than it was in 2005.

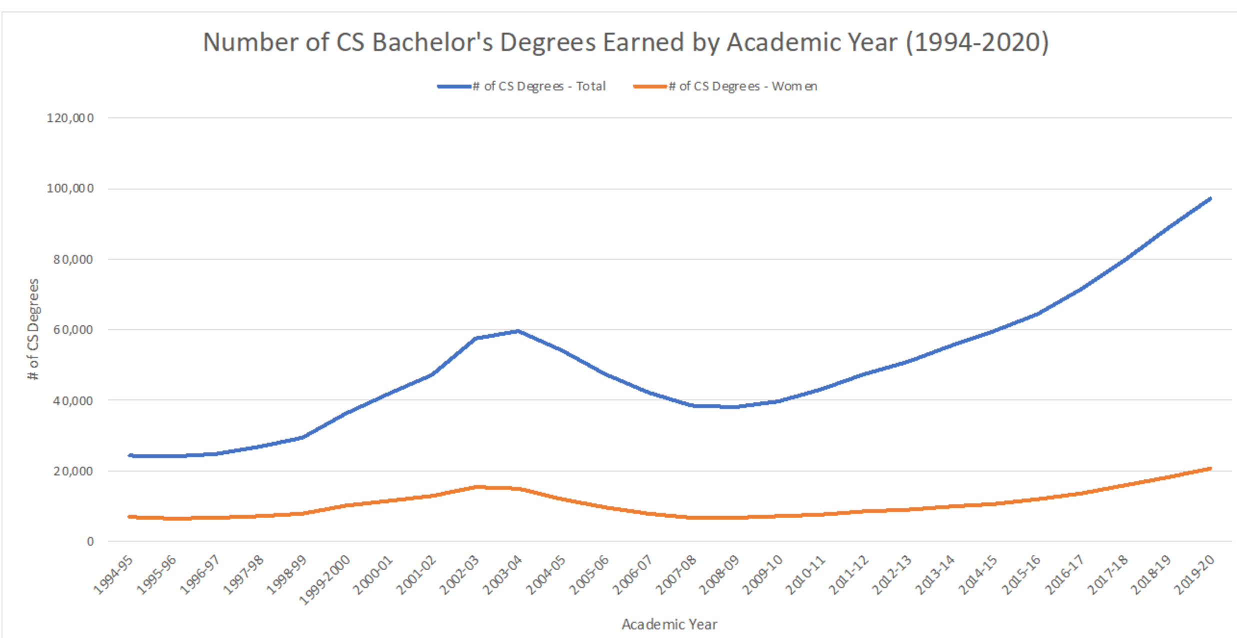

Figure 2-1. Total number of CS bachelor's degrees earned each year compared to the number earned by women, based on NCES data [1, 19, 21, 26, 27].

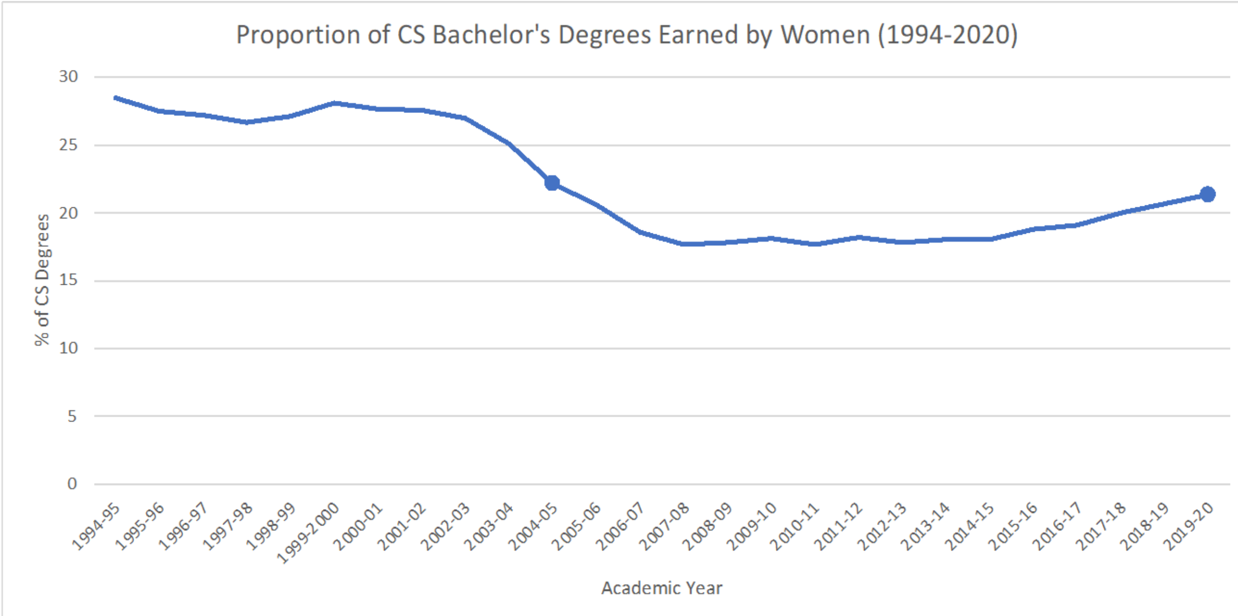

Figure 2-2. Proportion of CS bachelor's degrees earned by women over time, based on NCES data [1, 19, 21, 26, 27]. Years denoted by markers demonstrate that the proportion of women earning CS degrees in 2020 is less than in 2005.

While a variety of factors likely contributed to the shifting demographics of CS degrees over time, the changes to the public's perception of computer science described here are significant. Social expectations about who can or should be a computer scientist affect an individual's expectations about what they can or should achieve. There is a large body of research, including [28-30], dedicated to analyzing how societal gender stereotypes and conditioning impact individuals' educational and career decisions, particularly in relation to science, technology, engineering, and mathematics (STEM) fields [31-33]. While individuals may work to overcome these expectations, they still face constraints when entering spaces and filling roles that have been shaped, implicitly or explicitly, to exclude them.

2.2 Sense of Belonging in Computing

The cultural recoding of CS as a distinctly male interest shifted the American culture of computing itself, further disenfranchising women and others underrepresented in the field. The "hacker" and "CS wizard" stereotypes pervaded the classroom, creating an exclusive environment that valorized the idea of innate technical talent, which favored students who had early exposure to computer science as well as the financial means and access to infrastructure needed to cultivate that interest. While these masculine stereotypes of computer scientists have shifted slightly over time to the current cult of the "brogrammer" [34], the level of intimidation for newcomers to the field remains the same.

Sense of belonging, or the lack thereof, in computer science is the bedrock of exclusion. A study assessing effects on sense of belonging for undergraduate CS students at 15 U.S. universities for the 2015-2016 academic year characterized sense of belonging as "a fundamental human need that drives students' behaviors, particularly in environments where they may feel that they do not belong" [12]. There is a breadth of literature demonstrating that the degree to which students feel welcome and valued in a classroom environment impacts their ability to excel in that environment. A 2001 survey study of undergraduate students at University of

Wisconsin-Parkside identified negative stereotypes and low confidence as two main reasons behind the low representation of women in CS education [7]. Each of these factors relates to sense of belonging; stereotypes influence which groups of students can envision themselves attaining success in CS, while lacking a sense of belonging may decrease students' confidence in their capabilities.

As revealed through an interview study conducted by professors at Carnegie Mellon University's School of Computer Science in 2000, male and female students generally convey different attitudes about computing—attitudes shaped by the social and psychological factors that construct their cultural and personal understandings of computer science, which in turn shape students' self-perceptions of their aptitude for and interest in CS [5]. According to the University of Wisconsin study, the "geek mythology" that casts computer scientists as highly intellectual but lacking interpersonal skills is at odds with the gender stereotypes traditionally assigned to women [7]. Even more so than other STEM fields, CS is widely perceived as male-dominated, and women who succeed in the field are viewed as exceptions to the rule.

An early love of computing was common among male interviewees in the Carnegie Mellon study, portrayed as a "part of their identity" [5]. In comparison, women were far less likely to enter college with prior CS experience. While the researchers found no correlation between level of prior experience and academic success in the field, they did find that this experience gap affected female students' perception of their capacity for success. Many women described feeling that they were slower to grasp concepts than their male classmates, who seemed to excel without effort—reflecting and reinforcing the implication behind "CS wizard" stereotypes that men are innately gifted at computing.

In reality, male students tended not only to have more experience with CS but also to act overly confident in their expertise, whereas female students tended to second-guess and downplay their skills. Due to the strong cultural coding of modern computer science as men's work, women do not experience the same expectation of success in the CS classroom as their male peers. As summarized by Margolis: "Men who face difficulties with coursework do not struggle under the additional burden of the presumption that they are somehow inferior by virtue of their gender; nor do they have the pressure of feeling they are representative of their gender" [5].

In addition to the experience gap, CMU's interviews with female students revealed a perceived gap in passion for the field. Of the female CS majors interviewed, 20% admitted to questioning whether they belonged in the field due to the perception that their passion for CS was less intense than that of their male classmates. The interviews also revealed that female CS students were significantly more likely than male students to draw connections between their interest in CS and their interest in other disciplines, focused on contextualizing CS with other fields in addition to developing technical competencies.

Although technical and contextual knowledge are both important to computer science work, these insecurities about gaps in their experience and passion eroded female students' confidence and sense of belonging. The University of Wisconsin study not only showed that women's computer science confidence was significantly lower than men's overall, but that *the confidence of women CS majors was actually lower than that of male non-majors* [7]. If women who persisted in majoring in CS so clearly lacked a sense of confidence in their skills and of belonging in the field, one can only imagine how many female students were discouraged from pursuing CS by those same insecurities.

2.2.1 Intersection of Gender, Race, and Other Identities

Though this analysis focuses primarily on gender as a category of difference, race and class also play significant roles in finding a sense of belonging in CS. Common conceptions of the "CS wizard" are not only male but also likely White. As White women have faced significant disparities in employment opportunities, Black workers have to an even greater extent [35-36], particularly Black women [37]. This is true—though distinct in its history and effects—for members of many racial and ethnic minority groups, including Hispanic/Latinx, Asian/Pacific Islander, Native American/American Indian, and multiracial identities [38-39].

As demonstrated in Figure 2-3, which breaks down demographics of 2019-2020 undergraduate CS degree earners by gender and race [1], women are consistently underrepresented in their share of CS degrees, across racial and ethnic groups. Asian/Pacific Islander women are the exception to this trend, with their representation of CS degree earners being 1% higher than their share of degree earners overall. White men account for the largest share (41%) of CS degree earners by far, while only accounting for 25% of all degree earners. While the gender divide is clear, it is reasonable to assume that many students from diverse racial and ethnic backgrounds grapple with their own unique challenges in entering a predominately White, overwhelmingly male space.

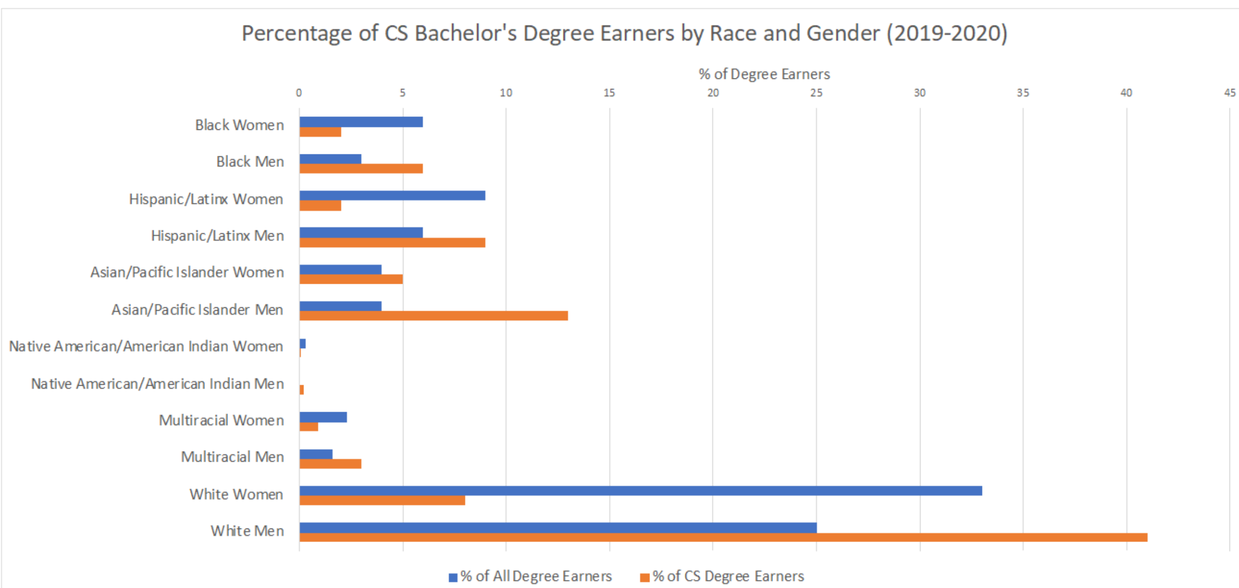

Figure 2-3. Breakdown of CS bachelor's degrees awarded for the 2019-2020 academic year by race and gender of degree earner, based on NCES data [1].

For women of color, barriers to entry into the field of CS have historically been higher than those for White women. Women's representation in collegiate CS education peaked at 37% in 1984, when White women comprised 43% of all degree earners [19, Table 256]. At the time, Black women constituted only 3.6% of degree earners, while Hispanic/Latinx and Asian/Pacific Islander women each accounted for just over 1% of all degree earners. Women of color faced a number of constraints to entering higher education—lack of access to high-quality primary education, financial pressures and family responsibilities, outright racial discrimination—due to historic and systemic racial oppression that White women did not [39]. While NCES has no data available on the breakdown of CS degrees awarded by race and gender for 1984, one can deduce from the low representation of women of color as degree earners overall that the vast majority of female students comprising that 37% were White.

Women of color continue to face barriers at the intersection of their racial and gender identities that White women either do not face or experience to a lesser extent. “Inside the Double Bind: A Synthesis of Empirical Literature on Women of Color in STEM” [40], the result of an NSF-funded project to distill insights on the challenges faced by women of color in STEM fields, sheds light on some of these barriers in CS. The synthesis describes how the prevailing CS culture, which champions a “supposedly meritocratic” emphasis on classroom performance and grade point averages that “nevertheless ignores the social realities of racism and sexism in science environments,” impacts women of color.

In this culture, which is particularly prevalent at Predominately White Institutions (PWIs), women of color face unique forms of social isolation and stereotyping—driven by the compounding experiences of being one of few women and one of few students of color in a classroom. One study [41] surveyed in the “Inside the Double Bind” literature review captured the following characterization of a black woman’s experience in CS: “As far as being a woman, I don’t think they expect too many women in that area; as far as [being a] black woman, they don’t expect you to be there at all.” This culture creates additional work for women of color in CS—work not just to succeed academically but to do so in an often-lonely environment, with significant pressure to disprove the unchecked biases of White professors and peers.

When evaluating the diversity of students represented in computer science, it is also important to consider the role of socioeconomic class, particularly in relation to developing CS experience prior to entering college. Honing CS knowledge and skills from an early age requires the expendable budget and time to invest in computing technologies—resources that students from low-income families may not have. Students from under-resourced school districts are less likely to have access to computer science courses or tools and to gain CS experience in middle or high school. At colleges and universities, CS programs tend to be time-intensive and relatively rigid when compared to other, especially non-STEM, disciplines. Students who must work through school to finance their education and support themselves or their families may struggle to balance the CS coursework and schedule with their other obligations.

According to 2020 U.S. Census Bureau data [42], the median incomes for Black and Hispanic/Latinx households were less than 75% of the median income for White households. Of the major racial groups examined, the data reveals that Black and Hispanic/Latinx communities also experienced the highest poverty rates. These economic disparities, another consequence of systemic racism, also impact the experience of women of color in CS. As identified by “Inside the Double Bind,” the pressure to balance family or work obligations with a rigid academic program is another prevalent hurdle for women of color [43].

Additionally, women of color are more likely than their White peers to enter the CS workforce through nontraditional pathways (from community college, without a degree, or with a non-CS degree) and later in life. Findings from “Inside the Double Bind” indicate that the environments of community college CS programs, which are generally much more affordable than university programs, tend to be more collaborative and racially diverse than the more individual and competitive environments found at four-year colleges and universities [40]. Overall, these studies show that the persistence of women of color in CS, even more so than for White women, hinges on personal drive and resilience—in spite of, rather than supported by, the institutions and culture of computing.

Computer science is a field with high barriers to entry—the height of which are multiplied for some students based on intersecting elements of identity. When overlapping, the social and economic factors that shape who is interested in pursuing and has access to CS education often lead to the exclusion of already marginalized identities.

2.3 Factors Influencing Women's Participation in Computing

From this analysis of sense of belonging for women in collegiate CS education, some important factors emerge, namely:

- Prevailing stereotypes about and the culture of computing.
- The level of a student's CS experience.
- The nature of a student's interest in CS.
- The level of a student's confidence in their CS competencies.

Each of these factors not only contributes to the overall sense of belonging for female students in CS but also interacts with and modulates the other factors.

Stereotypes of CS as a male-dominated, male-specific interest may discourage women from pursuing the field early on, influencing their lack of CS experience prior to college. Once at university, women students may feel intimidated by an academic culture that promotes individual technical excellence, "hackery," and showing off. The emphasis on coding for coding's sake may not resonate with the interests of many female students, who are more likely to face the gendered social pressures to orient their lives and careers around caring for others [31]. Further, the rigidity and intensity of the CS culture and curriculum may exclude female students who are new to computing or have significant financial and family responsibilities in addition to their coursework. Any departure women feel from norms of the CS classroom may decrease their confidence in their ability to achieve success there.

As discussed, the historical factors that have shaped public perceptions of CS and the current culture of computing have diminished the availability of CS education to women and other marginalized groups. To be effective, any strategy for broadening participation in CS must address the root of the issue: sense of belonging. Targeting the factors outlined here—by reducing the gender experience gap or expanding the scope of CS education beyond technical excellence to appeal to a wider range of interests—can help to bolster sense of belonging for students currently underrepresented in CS. Further, as demonstrated in the next section, implementing comprehensive changes to CS education that address each of these factors can lead to significant progress for increasing diversity, equity, and inclusion (DEI) in the field.

3 Strategies for Broadening Participation in Computing

The strategies identified here for increasing the representation of women in computer science education are derived primarily from the case studies of Carnegie Mellon University and Harvey Mudd College. Both schools recognized the gender gap in the CS major and instituted structural changes to their CS programs to reduce it.

Carnegie Mellon began investigating the issue in 1995, when women comprised only 7% of the school's entering class of CS majors [45]. Allan Fisher, Associate Dean for Computer Science Education at the time, solicited the help of Jane Margolis, a social scientist with expertise in gender equity in education, to conduct a study analyzing the low representation of women. The study [8] revealed factors like those outlined in this analysis, including the gender experience gap, female students' lack of confidence, and issues with the CS classroom environment and pedagogy. In response, CMU set out to reform its CS program, instituting revisions to its recruitment and outreach efforts, admissions process, curriculum, and approach to community-building. With these efforts, CMU saw the percentage of women entering its undergraduate CS program rise to 42% by the fall of 2000. In addition to achieving this 35% increase in women's representation over a period of only five years, CMU has maintained its equity-focused research efforts to this day. From 2017 to 2019, the representation of female students in CMU's undergraduate CS major lingered just below 50%, nearing gender parity [8, 18].

Perhaps even better known than CMU's success story is that of Harvey Mudd College. In 2005, women accounted for only 10% of the school's CS majors [11]. That year, HMC started implementing changes to its CS program, with the aim of making it more approachable and attractive to female students [10]. HMC's three-pronged methodology focused on restructuring its introductory CS courses to better engage female students, increasing their sense of confidence by providing research opportunities for students with less formal CS experience, and helping female students to forge connections with their peers and with mentors working in the field. The percentage of women in HMC's CS program had doubled by 2006—just one year after initiating the changes—and neared 40% by 2009 [11]. HMC has not only received high praise over the years from many educators and news outlets [45-46] but has also established the gold standard that other schools seek to emulate [47]. Representation of women in the school's CS major has continued to grow over time, reaching 56% in 2018 [48].

These two schools are not the only successful case studies for increasing the representation of women in undergraduate CS; in fact, HMC received a grant from the National Science Foundation (NSF) in 2010 to export its restructured introductory course to other universities [11]. One of the adopters, Northwestern University—which has a significantly higher student population than Harvey Mudd and nearly double that of CMU—saw the percentage of women in its CS major double from 15% in 2011 to 30% in 2019 [49]. That said, the changes made by CMU and HMC not only reflect but have furthered the research foundational to increasing gender equity in CS education. By examining these case studies in the context of that broader body of research and against the factors outlined in the previous section, five core strategies for increasing women's participation in CS education emerge.

3.1 Strategy 1: Reform Computer Science Curriculum

While many of the actions taken to increase the representation of women in CS majors focus on shifting the culture of CS, structural change requires a holistic approach that addresses the very framework of CS education, which reflects, influences, and reinforces aspects of the current, exclusionary computing culture. Both CMU and HMC instituted changes to their CS curricula, most of which were designed with the goal of making CS courses more accessible to students at all levels of experience.

In HMC's case, curricular changes began with the reimagining of the school's introductory CS course. Some of the alterations may seem relatively minor—such as renaming the course from "Intro to Java" to "Creative Problem Solving in Science and Engineering Using Computational Approaches" or changing the language of instruction from Java to Python [50]. However surface-level these changes may seem, the CS department made them with the intention of making the introductory course more approachable, particularly for students with less CS experience. HMC recognized how even small steps like removing technical jargon from a course title might impact students' perception of a class and reduce their level of intimidation in enrolling. Opting to teach the course in Python—a language less rigid than Java, C++, and other languages commonly included in the CS curriculum—and creating separate tracks for students based on level of prior experience with CS also made for an easier transition into computing by newcomers [11].

Beyond these material changes, HMC also restructured its CS curriculum to embrace a different educational approach. Led largely by Maria Klawe, renowned computer scientist and (at the time) new president of the college, HMC redesigned its introductory coursework and programming to emphasize computational approaches to problem solving over learning to code [11]. The new curriculum championed a breadth-first approach [51] to computing geared towards expanding students' understanding of what computer science is and how it can be meaningfully applied to real-world problems. The breadth-first approach provides students with context that is often absent from traditional introductory CS coursework, which often focuses on teaching a limited set of language-oriented technical concepts to cultivate students' programming abilities.

Learning to code is fundamental to computer science; that said, the discipline of computer science encompasses much more than programming. Limiting the scope of what may serve as students' initial exposure to CS to learning how to program also limits students' perspectives on the goals and success metrics for CS, appealing to those who embrace the culture of technical excellence while discouraging students with diverse experience and interests. A narrow focus on abstract technical concepts and learning to code highlights the experience gap, making students without prior programming experience feel behind before they have truly begun in their CS education. In addition to creating an intimidating environment for newcomers, findings from Margolis and Fisher at CMU [8] show that overemphasizing technical knowledge without addressing the social context in which it operates disenfranchises female students in particular. As explained in a position paper authored by an undergraduate member of CMU's CS advisory council, "some men seem to be fascinated by the machine itself and being able to take control of the machine," whereas women "seem to see the computer as a tool to achieve what they wanted to do" [8].

The breadth-first approach [51] introduces students to CS from the standpoint of what they can achieve with computing, helping them build the skills to actualize those goals along the way. The approach does not deprioritize technical knowledge but rather contextualizes and resituates that knowledge in a way that is more accessible and appealing to a diverse pool of students. In fact, HMC's revised curriculum requires students to write more computer programs than they had in the past iteration of the curriculum—just in a more project-based, multidisciplinary fashion [11].

Infusing interdisciplinary perspectives into CS education is another curricular strategy leveraged by HMC, CMU, and other analogs. Developing the connections between CS and other disciplines not only helps to situate CS in its social context but also to expose students from other majors to CS competencies that they otherwise might never have explored. Another leader in the education gender equity effort, the University of British Columbia (UBC), introduced mini-streams—series of courses fusing CS with related disciplines, particularly those in the humanities and social sciences [11]. Introducing pathways to combine CS with other disciplines further expands the focus of the CS curriculum to meet the interests of those outside of the traditional CS bubble.

These reforms to the CS curriculum address each of the factors limiting women's participation in computing. Changes to a course's name, content, and goals—such as those undertaken at HMC—can increase the approachability of CS for newcomers and better enable the success of students at all experience levels. Tracking sections of the introductory course by experience also helps to increase students' confidence by narrowing their perceptions of the experience gap—ensuring all students have access to the appropriate level of instruction and are surrounded by peers of similar skill levels. Expanding the scope of what introductory CS coursework covers can also help to deemphasize elements of the prevailing CS culture that disillusion women and other underrepresented students from pursuing the field, shifting the reality of CS classes away from the stereotype. This does not mean creating a curriculum that is unwelcoming to students driven by the desire to achieve technical excellence but rather one that welcomes students with diverse natures of interest in CS and aims to cultivate all those interests.

3.2 Strategy 2: Encourage Inclusive Classroom Dynamics

Though curricular changes can affect changes to the culture of CS, they do not amount to cultural change. Thus, it is important that curriculum reforms are accompanied by changes to CS pedagogy and the classroom environment. To a large degree, perpetuation of the "tech genius" stereotype in CS hinges on who buys into it and how adherence to that stereotype is rewarded.

Reflecting on hallmarks of the CS classroom environment reveals some of the utility behind prevailing stereotypes of CS students. Students in CS courses, as with many engineering disciplines, face hefty workloads, rigid lab and assignment schedules, and intense pressure to succeed. While some of the coursework may be collaborative, there is an undercurrent of competition between students, who are often graded on a curve [52]. Due to the steady stream of work and low exam averages, it is not uncommon for students to feel as if they are failing all semester, only to experience relief upon receiving their final grade. This environment is conducive to the cult of the "tech genius," creating a pedestal for the students who have more CS experience, who appear not to have to work as hard, and who *just get it* [53].

Of course, there are students in every discipline who take to it more naturally than others. What makes this distinct in CS is that these "tech geniuses" seem to satisfy an archetype central to CS culture, one that characterizes technical talent as innate and decidedly male. For women and other students traditionally excluded from the "CS wizard" stereotype, comparison to that ideal—by faculty, their peers, and themselves—in a highly pressurized, competitive environment is discouraging to say the least. In their paper promoting a systemic change model to increase gender equity in undergraduate computing [9], authors Barker, Cohoon, and Thompson discuss how female students have a decreased "tolerance" for receiving low grades than their male peers, given that such grades "appear to confirm stereotypes about their lack of aptitude for computing." In the already high-stakes environment of a CS classroom, the stakes are even higher for women students—likely higher than their male classmates or faculty realize.

Further, research shows that faculty attitudes also have an impact on the persistence of female students in computer science. In 2001, Joanne McGrath Cohoon, a sociologist and education equity researcher, conducted an interview and survey study of 23 CS departments across the state of Virginia [6]. The study aimed to identify factors contributing to gendered attrition (GA) rates—differences between male and female attrition rates—in undergraduate CS (summarized in Figure 3-1). Regarding the effect of faculty attitudes, Cohoon's study shows a notable correlation between attitudes that "expressed strong appreciation for their female students' abilities and work styles" and low rates of GA. In contrast, "departments where most faculty reported no difference between their male and female students' abilities, or some female disadvantage, were the departments that lost women at disproportionately high rates." Faculty's perceptions of and attitudes towards their students have an impact on those students' experiences and persistence in the field.

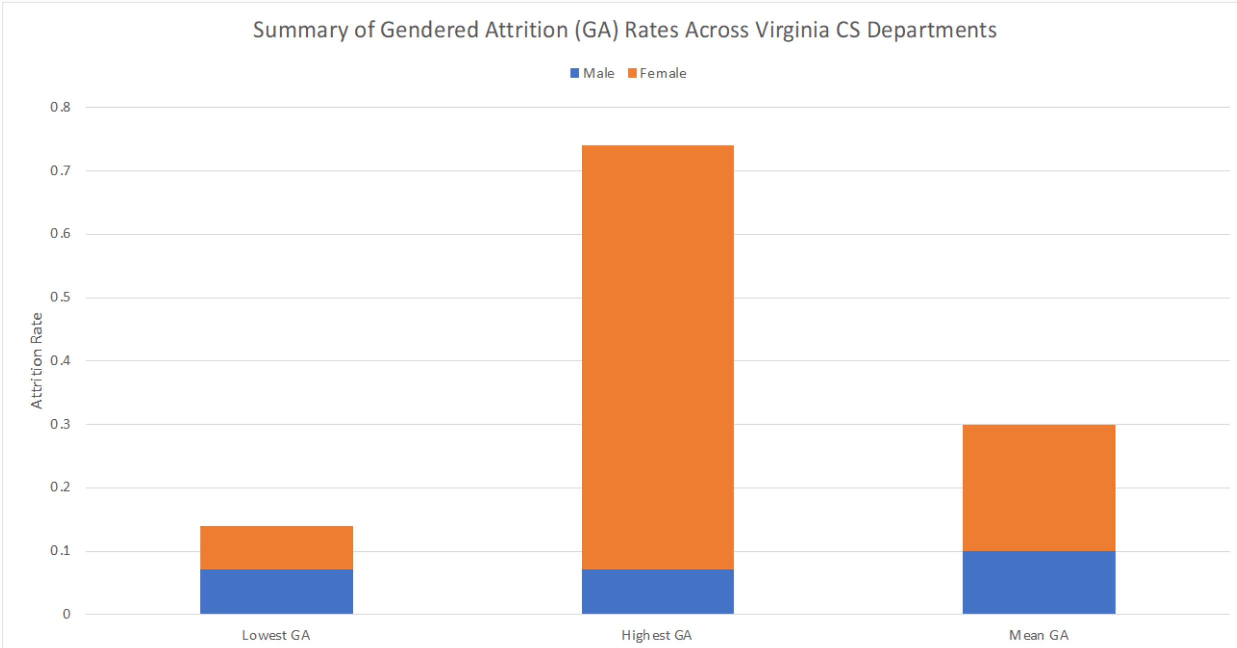

Figure 3-1. Summary of lowest, highest, and average rates of gendered attrition (GA) from Cohoon's study of 23 Virginia CS departments [6]. As shown, on average, the attrition rate for women studying CS at a Virginia university was double that of the attrition rate for male students.

While it is important for faculty to check their gendered assumptions and biases before entering the CS classroom, Cohoon's study also reveals harmful notions that relate directly to the "tech genius" stereotype. Cohoon's data analysis demonstrates that CS departments also lost female students at disproportionately high rates "when faculty strongly believed that innate ability was responsible for student success." In a cross-discipline comparison, Cohoon found that this faculty belief in innate talent was more prevalent in CS than in other STEM fields, like biology.

Once aware of the power and harms presented by these stereotypes and biases, there are measures professors and other faculty members can take to create a more welcoming and productive classroom environment for all CS students. One of the strategies employed by HMC was to stop rewarding "tech genius" behavior by actively discouraging the most experienced students from showing off in class or dominating classroom discussions [11]. HMC found that "eliminating this 'macho' effect" greatly improved the culture of their CS classes and created "a more supportive learning environment for all." Disincentivizing the practice of showing off in class also reduces some of the emphasis placed on individual achievement, paving the way toward a more collaborative and less competitive classroom environment. This lays the groundwork for faculty to introduce other teaching methods that help students conceptualize their success in partnership with rather than in opposition to their peers.

Instructors can also work to shift the success metrics for CS from getting the right answer or the best grade to demonstrating the masterful application of CS competencies to solve a problem [54]. This goes hand in hand with the proposed revisions to CS curricula that prioritize building students' understanding of modern computational thought. Having students focus on developing a problem-solving mindset and explaining their thought processes more so than reaching the best, most efficient solution right away cultivates a more flexible learning environment, which extends less of an advantage to students who might fit with or aspire to the "CS wizard" role.

By fostering inclusive classroom dynamics that counteract restrictive notions of what constitutes success in CS, faculty can help to reduce the factors that limit women's participation in computing. These changes to the classroom environment not only make CS courses more welcoming to students with less experience and lower confidence in their abilities but also combat the reasons for those students' hesitation at their core. So long as classrooms are structured to reward adherence to CS stereotypes, those stereotypes will continue to proliferate—to the harm of all students who fail to fit the mold.

3.3 Strategy 3: Increase Institutional and Classroom Support

When considering how to address the gendered gaps in CS experience and confidence, HMC and CMU recognized that, even with curricular reforms and changes to classroom dynamics, some students simply required more support adjusting to the CS environment and mastering concepts. CS courses tend toward high enrollment and large class sizes, which helps to meet the increasing demand by students to develop computing skills but also limits the level of individualized instruction.

While constraints on individualized attention and support affect all CS students, research shows that student-faculty interaction is especially important for female students. According to Fisher and Margolis of CMU [8], although reducing the confidence gap is often viewed as out of CS faculty's scope, "confidence is closely linked with pedagogy and relations with faculty." They cite research by Seymour and Hewitt on why undergraduate students leave science fields, which identifies a lack of student-faculty interaction and mentorship as a primary reason for female students' lack of confidence. Further, the results of Cohoon's study of CS departments across Virginia [6] show a corresponding decrease in gendered attrition with an increase in the number of hours and number of female students mentored by faculty—regardless of the level of women's enrollment. These trends are understandable, given all the reasons previously discussed for why women generally enter the CS classroom with lower confidence than their male peers. In an environment in which female students are likely to feel isolated by their peers, connections to faculty as sources of support and reassurance are more important than ever.

In addition to the emotional or psychological benefits of student-faculty interaction, there are obvious practical benefits to increased mentorship. Those inexperienced with CS, as is the case for many female students, may require more individualized learning time to grasp technical concepts. Creating opportunities for students to connect with their instructors and administrators improves students' comfort level in the CS classroom, thereby increasing their likelihood of asking for help when they need it.

While decreasing class sizes and the student-faculty ratio would be an ideal solution to this problem, this may not be possible for many CS departments due to the high demand for CS enrollment and resource constraints. CMU and HMC found success by creating and promoting more opportunities for one-on-one time between students and instructors or teaching assistants wherever possible, for example by expanding their offerings of course sections, labs, and office hours [8, 11]. In the face of time and resource constraints, providing this extra support may require reducing the regular workload for students and faculty. For its revised introductory CS course, HMC added a weekly optional two-hour lab session for students to work on one of their homework assignments with faculty supervision [11]. Students who attended received full credit for the problem they worked on during the lab, regardless of whether they reached a complete solution. This approach not only reduced the workload for less experienced students but provided them with more opportunities to connect with faculty outside of class and more support in mastering difficult concepts.

It is important to note that instituting effective support systems for students requires not only time and resources but also sincere consideration from faculty. This relates to faculty attitudes discussed in the previous section [6], as building relationships with faculty members who carry unchecked assumptions that align more to traditional CS culture than to the needs of their female CS students will serve to decrease rather than bolster women's confidence. It is challenging to be underestimated by one's peers but even more damaging to a student's confidence to face misjudgment by their professors and administrators. When provided in earnest, individualized learning time and increased faculty support have proven highly effective for mitigating the experience and confidence gaps faced by female CS students.

3.4 Strategy 4: Provide Opportunities to Gain Practical Experience and Exposure

Another effective strategy demonstrated through these case studies for reducing the gender experience gap is establishing programs to help prepare female students for entering the CS workforce. That preparation entails providing ways for female students to develop their skills by working on real-world research problems, gain insight into what career opportunities are available to them, and connect with women currently working in the field.

One method that proved successful for HMC in achieving this goal was the development of research courses and internships marketed to less experienced CS students. When researching gender equity in CS prior to implementing their reforms, HMC found that providing undergraduate students with research experience positively impacts student retention in CS [10]. Since research opportunities are typically only available to upper-class CS students who have completed the major prerequisites, HMC instituted a summer research program targeted towards first-year female students. The school hired these student researchers to work on projects exploring burgeoning topics in computing, including artificial intelligence, game systems, and robotics, and found that—despite the students' relatively low experience with CS—they made significant progress on their research problems.

In addition to building their technical knowledge and skills, these research positions also provided female students the opportunity to develop close mentor relationships with CS faculty members and upper-class students [10]. Results from a survey conducted by HMC to assess the impact of changes to the CS department show that these summer research opportunities played an influential role in many women's decisions to become CS majors. Beyond that, the research opportunities provided female students with the work experience needed to pursue industry internships in subsequent school years and job opportunities further down the line.

Another measure taken by both HMC and CMU to prepare their female students for the CS workforce was to advertise and sponsor student attendance at conferences and events promoting DEI in the field. During the overhaul of its CS program, HMC began sponsoring attendance for first-year female students at the Grace Hopper Celebration of Women in Computing (GHC), an annual conference that boasts the world's largest gathering of women technologists, designed to showcase women's recent contributions to the field and provide networking and mentorship opportunities for all attendees [55]. HMC hoped that introducing students to women computer scientists and their work "would reinforce *experientially* the opportunities [they] sought to present in the curriculum" [10]. This became such a successful recruiting tactic for HMC's CS department that they began contacting incoming students the summer before they started college, attracting them to CS courses with the opportunity to attend GHC.

CMU has also sponsored attendance for female students at GHC, including for the 11 students the school brought in 2000 to share the research and changes led by Fisher, Margolis, and Blum for increasing gender equity. The school still maintains a large presence at GHC today, having sponsored attendance for over 80 students in 2019 [55]. In the words of Carol Frieze, then director of CMU's student interest group for women in CS: "For students, attending Grace Hopper and being among so many incredible women leaders from industry and academia reaffirms their sense of belonging in computing fields, which are still heavily male dominated" [47, 55].

In addition to GHC, there are a number of other organizations and programs that provide learning opportunities, support, and resources for women and other underrepresented students in CS, including the Association for Computing Machinery - Women (ACM-W) [56], National Center for Women & Information Technology (NCWIT) [57], and Advancing Robotics Technology for Societal Impact (ARTSI) [58]. Promoting and sponsoring connections to these networks situates students, who might otherwise feel isolated in CS, within a community of shared interests and experiences.

Offering female students practical opportunities to develop their CS skills and to gain mentorship from other women technologists not only helps to decrease the gender experience gap but also to pique women students' interest in CS. Making progress on a real-world research problem or finally seeing the representation they lack in the CS classroom at an event like GHC also increases female students' confidence, enabling them to envision success for themselves in a field that may often feel isolating and discouraging. Overall, such programming serves to affirm for female students—whether through satisfaction with their own skills or connections with the broader community of women in CS—that this is a field where they can belong.

3.5 Strategy 5: Create and Promote a Sense of Community

Given that sense of belonging is a strong undercurrent to the lacking representation of women in CS, it stands to reason that measures to increase sense of belonging and community for female students provide some level of amelioration to most of the factors influencing women's participation in CS. One barrier to forging that sense of community is the low representation of women itself. Another key takeaway from Cohoon's research on gendered attrition in CS [6] is this: "The presence of female peers helped CS departments retain women at equivalent rates to men." Cohoon found that CS students rely on their peers for help with coursework, which—for women in CS—often means seeking help from male classmates, resulting in real or perceived, gendered judgment on their computing abilities. This presents a vicious cycle, in which the lack of female representation in CS classrooms drives women out of the discipline, further decreasing the representation of women.

The good news is that the opposite also holds true; increasing the representation of women in CS increases the sense of belonging and community for female students, thereby attracting more women to the field. The issue then hinges on laying the groundwork to build a sense of community for female students. Lenore Blum, esteemed computer scientist and former professor at CMU, addressed this issue by founding the school's Women in the School of Computer Science (Women@SCS) Advisory Council [8]. The Council (also referred to as the Committee) is comprised of undergraduate and graduate students from various years and backgrounds across the CS department [44]. As defined by Blum, the Council's initial objectives were to assess and fulfill the needs of women in CMU's CS department, with an emphasis on building community.

The Committee established a range of programs designed to support women pursuing CS—including a peer tutoring program, a "Big Sister/Little Sister" mentorship program connecting upper-class female students with their younger peers, and a series of social events [44]. These events often focused on forging mentor relationships between female students and faculty as well as between students and women computer scientists working in the field. By Fisher's and Margolis' assessment, the efforts of the Women@SCS Advisory Council served "to build the perception of 'critical mass,' breaking down the sense of isolation felt by some female students" [8]. By cultivating a sense of community amongst CMU's then small population of women CS students, the Women@SCS Advisory Council not only increased female persistence in the major but helped to attract more women to the field.

Essential to the Committee's success was support from the university and CS administration. As an Advisory Council, Women@SCS created a pipeline for female students to raise their concerns and ideas directly to the leadership of the CS department [8]. Taking direction from the students most impacted by issues of low representation is an effective strategy for meeting their needs and improving their experiences. That said, university institutions—and not their female students—ultimately bear the responsibility for creating systemic change. It is in partnership with CS administrations, rather than in opposition to or absence of support from them, that female communities within the department are most likely to thrive.

If universities are to reap the reputational benefits of increasing gender equity in their CS programs, then their faculty hiring, student recruitment, and admissions processes should reflect an actual commitment to increasing DEI within computer science. CS administrations should not only invest in student organizations that provide community for women in the major but also institute policies that encourage, rather than penalize, faculty engagement in and leadership of those efforts. For CS departments to demonstrate that they value women and other students underrepresented in CS, they must prioritize, finance, and reward activities that increase sense of belonging for those students.

3.6 Key Takeaways

Evaluating these strategies in aggregate reveals four underlying themes. First, each of the strategies requires university CS departments to undertake structural and cultural reforms. The strategies do not offer quick fixes but rather the building blocks of systemic change to collegiate CS education that create a more equitable learning environment. Embracing these measures necessitates that CS departments make an earnest commitment to addressing gender inequities that is grounded in action, not performativity.

Second, these structural changes reshape CS education from the standpoint of underrepresented or marginalized students in the field—particularly women. To increase gender equity in CS and make the discipline more inclusive, it is crucial to identify and prioritize the needs of students excluded by the current system. This should not come at a cost to male students who are already succeeding in the field; in fact, the research cited here shows that prevailing stereotypes and expectations of CS students can negatively impact students of all genders, confining them to a narrow mold. Aligning CS reforms to address the needs and perspectives of underrepresented student populations serves to expand that mold, ultimately benefitting all CS students.

Third, the strategies have a concomitant nature. All the strategies are interrelated, such that the successful implementation of one strategy lays groundwork that furthers the success of the others. This mirrors the overlapping, mutually constitutive nature of the factors limiting women's participation in CS. Addressing that network of issues requires a network of solutions, each of which tackles multiple factors and enhances the ability of the others to do the same. Figure 3-2 summarizes the potential of this matrixed approach to mitigate the factors limiting women's participation in CS education and increase their sense of belonging.

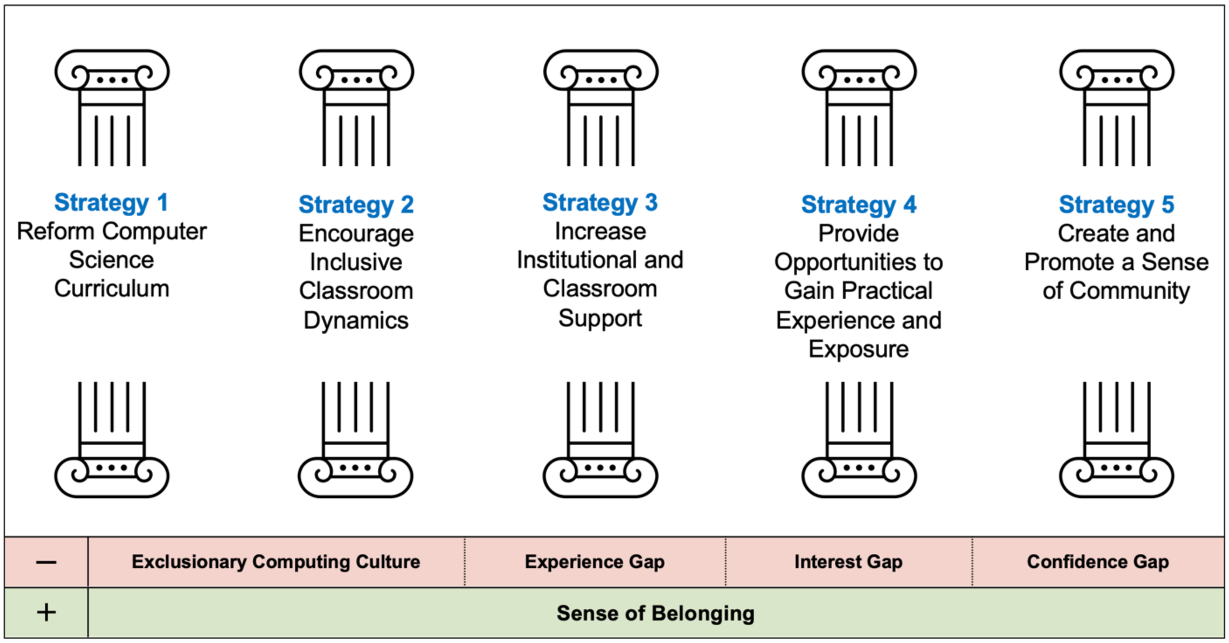

Figure 3-2. Overview of the five core strategies for increasing women's representation in undergraduate CS education. Each of the strategies serves to decrease the factors limiting women's participation in CS and increase their sense of belonging.

Fourth, each of the strategies identified in this document has had a proven impact on gender representation in CS education, as demonstrated by the case studies of HMC and CMU. Both schools conducted research throughout the process of reforming their CS departments to evaluate the effect of their changes [8, 11]. The results of that research, along with the marked increases in women's representation in each institution's CS program, clearly indicate the effectiveness of these strategies. In addition to the literature produced by CMU and HMC during their periods of reform, numerous articles have been published in the years since, revisiting, reaffirming, and promoting these core strategies—including [54, 59-60] to cite a few. Though the impact of adopting the strategies varies some by school, due to environmental and cultural variables that differ across campuses, there is evidence to support that colleges and universities besides HMC and CMU have found success with the strategies as well.

3.7 Impact and Propagation

After HMC received the NSF grant to export its revised introductory CS course to other universities in 2010, the school partnered with AnitaB.org, the organizer behind GHC, to launch the BRAID (Building, Recruiting, And Inclusion for Diversity) initiative in 2014 [61]. The program, which operated through the 2019-2020 academic year, promoted four commitments:

1. Modify introductory CS courses to better suit the needs of underrepresented students.
2. Lead outreach programs to engage high school students in CS and establish recruiting pipelines.
3. Institute programs to build confidence and community across underrepresented CS student populations.

4. Develop interdisciplinary CS courses and majors to appeal to a wider range of student interests.

BRAID derived these commitments from the changes implemented by schools it identified as Beacons—HMC, UBC, California Polytechnic State University, and the University of Washington—all of which saw significant increases to the representation of women in their CS programs. BRAID provided funding, guidance, and other support to 15 BRAID Schools that had committed to implementing the BRAID strategies and participating in a longitudinal study of their progress conducted by Momentum, a research branch of UCLA. According to the Year 6 BRAID Annual Report [62] released in 2020, overall computing enrollment at BRAID institutions saw an increase of 87% from 2014 to 2019. Over that same period, enrollment in CS at BRAID institutions increased by 139% for women overall, with a 127% increase for Black, Latinx, and Indigenous women. Neither the annual report nor the BRAID website provides insight into why the program has been discontinued.

Momentum, which formed through the BRAID initiative, has continued to conduct research on Broadening Participation in Computing (BPC) efforts [63]. The organization maintains a database of literature on BPC research, along with the results of its BRAID study and recent partnership with the Center for Inclusive Computing (CIC) at Northeastern University. Founded in 2019, CIC provides grants, research, and data analysis supporting the diversification of collegiate CS education to a network of partner schools, some of which had formerly taken part in BRAID [64]. Momentum is currently conducting a longitudinal study of undergraduate CS students at CIC partner schools, with a particular focus on the experiences of women of color [63].

Yet, despite decades worth of the research, funding, and success stories at individual institutions, women's representation in collegiate CS education at the national level has remained low and relatively stagnant. Two important questions follow from these findings: what barriers are preventing the adoption or success of these strategies and what can be done to mitigate them.

4 Barriers to Adoption

To understand the barriers to advancing gender equity, it is important to reconsider gender demographics in the current context of CS education. As discussed earlier, after hovering between 17% and 19% for over a decade, the proportion of undergraduate women CS degree earners rose to 21% in 2020 [21]. While that recent 4% increase in female representation may seem promising, it pales in comparison to the overall decline in representation since the start of the dot-com boom—which, in parallel to that decline, saw a 121% increase in the overall number of undergraduate CS degrees conferred [19, 26].

Today, CS is experiencing historic growth in enrollment, with CS enrollment rates currently doubling what they were at the peak of the dot-com era [65]. This level of growth, which started in 2006 but has accelerated since 2012, is not only unprecedented but also more or less ubiquitous, affecting undergraduate CS programs at schools large and small, public and private [65]. Growth in the production of CS degrees consistently quadruples that of overall undergraduate degree production [66]. Based on projections from the U.S. Bureau of Labor Statistics [67] that employment in computer and information technology jobs will increase by 15% from 2021 to 2030—significantly higher than the average across all occupations—demands for CS degree earners by employers and CS course enrollment by undergraduate students are unlikely to curb anytime soon.

While the field has undergone massive growth over the past couple of decades, the representation of women in CS education and the male-dominated culture of computing have experienced little change at the macro level. Contemplating the relationships between these factors reveals two major considerations that present obstacles to successfully adopting the strategies for reshaping CS education:

1. Resource constraints schools face in responding to the increased enrollment demand.
2. A lack of incentives motivating schools to undertake structural changes to their CS programs.

4.1 Barrier 1: Balancing Resource Constraints With Increased CS Enrollment Demand

While growth in the demand for CS education may present hope for the diversification of the field, increases in enrollment impose a variety of constraints that may cause schools to sideline rather than strengthen their efforts to increase gender equity in CS. As summarized by Carla Brodley [68], the executive director for CIC at Northeastern, "the crux of the challenge for university administrators is they cannot easily—or quickly—adapt their business model to changes in student demand." While metering university resourcing to match student demand is challenging across all disciplines, Brodley argues that it is especially difficult in the case of CS—particularly when it comes to attracting faculty. As shown in Figure 4-1, growth in the average number CS majors from 2006 to 2015 greatly outpaced growth in the average number of CS teaching faculty [69]. Since universities cannot compete with the salaries offered to candidates by industry employers, faculty positions in CS can take longer to fill than those in other departments.

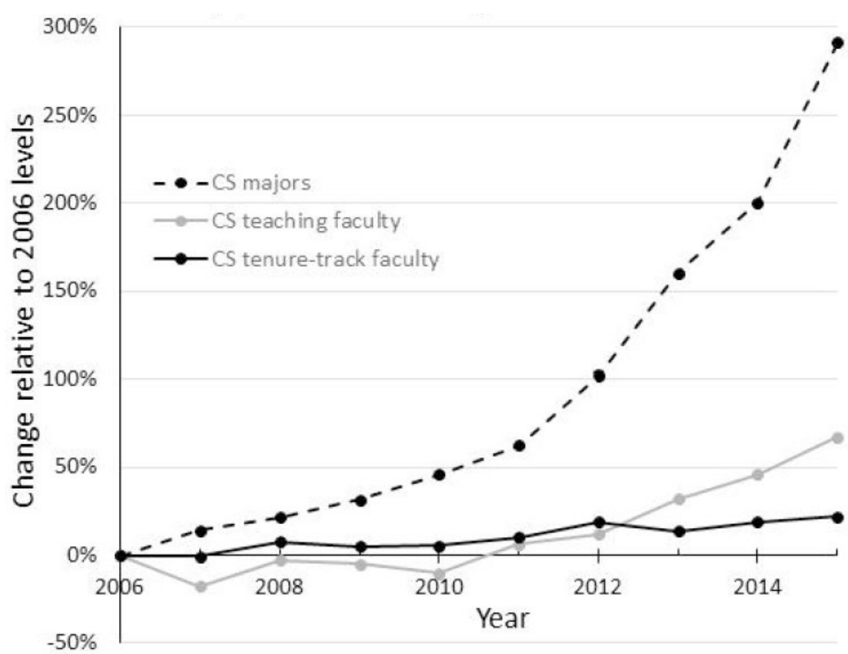

Figure 4-1. Chart from a report issued by the National Academies of Sciences, Engineering, and Medicine (NASEM) on the undergraduate CS enrollment boom [69], comparing trends in the average number of CS majors with the average number of CS faculty.

Unless department funding and hiring keep pace with increases in enrollment, schools must stretch their existing resources thin to support a rapidly expanding number of students. Measures for doing so—increasing class sizes, instituting caps on enrollment, reducing funding for DEI programs—tend to limit or directly counteract the core strategies identified for increasing the representation of women and other underrepresented students in CS. This incongruency between strategies for meeting increased enrollment demand and strategies for BPC poses a significant barrier to advancing gender equity.

According to a report issued by the National Academies of Sciences, Engineering, and Medicine (NASEM) on CS enrollment growth: "There is a very real possibility that the state or culture of academic computer science was or became somehow uniquely discouraging to women at times when enrollments surged" [69]. Research conducted by Momentum [66] supports this statement, showing that enrollment booms in CS are often followed by "sharp" and "disproportionate" decreases in the representation of women, Black, Latinx, and Indigenous students. Women's representation of CS majors dropped from 35% at the start of the dot-com boom to 12% by its end [70]. Additionally, from 1994 to 2000, the percentage of CS degrees earned by Black students decreased from 10% to 8.5%, despite increasing across all other disciplines [66]. Examining the interplay between institutional responses to increased enrollment and the strategies for increasing gender equity in CS helps to elucidate the constraints that arise during enrollment booms.

4.1.1 Increasing Class Sizes

Increased enrollment and difficulty filling CS faculty positions may cause schools to increase class sizes for CS courses. Increasing class sizes decreases students' potential for individualized learning opportunities and mentorship from CS faculty, who face a growing number of demands on their attention. Given how important student-faculty interaction is for women and less experienced CS students, reducing those opportunities undermines efforts to increase institutional and classroom support for underrepresented students (Strategy 3).

Further, increased class sizes may highlight demographic disparities in class composition, making underrepresented students feel out of place. Cohoon's study of CS departments across Virginia [6] found that gender composition is the "single strongest" and "most consistent" factor influencing the retention of women in CS. This is why building a sense of community for female students (Strategy 5) is so important; creating a support network that helps women persist in CS provides some level of representation needed to attract other women to the major. While women are generally underrepresented in CS classes of all sizes, it may feel more pronounced or overwhelming for students—in a classroom of hundreds of students—to see only a handful of others who look like them, decreasing their sense of belonging and community.

4.1.2 Instituting Enrollment Caps

Another common response to increased enrollment demand, which Carla Brodley of CIC identifies as the most popular across North America [68], is introducing enrollment caps, which means establishing a minimum GPA required for students to enter the CS major. According to Brodley, the GPA evaluated for enrollment is typically calculated based on a student's grades in the pre- and co-requisite courses for the CS major. This means that a student's ability to major in CS depends entirely on their grades in a handful of introductory CS and mathematics courses, which grants a clear advantage to students coming to college with prior CS experience, exacerbating the experience gap.

Thus, this response undermines the efforts of all strategies for advancing gender equity that aim to mitigate the experience gap (Strategies 1-4), particularly that which advocates increasing institutional support for underrepresented students (Strategy 3). In this case, female students are unlikely to benefit from the increased individualized learning and support found in major courses if they are precluded from pursuing the CS major in the first place. This approach puts less experienced students in a bind, such that if they cannot catch up quickly, they lose the chance to try at all. Raising the barriers to entry for majoring in CS may discourage students who lack prior CS experience or confidence in their CS skills—as is often the case for women—from even enrolling in introductory CS courses, completely limiting their exposure to the discipline. This intimidating posture towards newcomers poses a foil to all efforts geared towards attracting more students of underrepresented identities to CS.

In addition to disadvantaging students with less CS experience and confidence, enrollment caps also likely increase the competitive atmosphere of introductory CS and other gateway courses required to enter the major. As characterized by Brodley, enrollment caps introduce "risk" into knowledge sharing and collaboration between students [68]. Students are disincentivized from helping each other learn when they perceive the successes of others as threatening their own ability to major in CS. This constrains the ability of faculty and students to encourage inclusive classroom dynamics (Strategy 2), amplifying rather than reducing the competitive culture of computing that disenfranchises women and other students underrepresented in the discipline.

4.1.3 Diverting Resources from BPC Initiatives

A straightforward response to resource shortages caused by increased enrollment is to divert resources allocated for BPC efforts towards the department's essential functions, such as course instruction. Withdrawing resources from DEI efforts negatively impacts all strategies for increasing gender equity. This might mean reducing funding for programs—like those creating research internships for first-year CS students or sponsoring student attendance at Grace Hopper—that are designed to provide women with opportunities to gain practical CS experience (Strategy 4). Reductions in funding may also limit departmental programs and events aimed at building community for students underrepresented in CS (Strategy 5), shifting even more of the burden for community-building onto those students themselves.

That said, disinvestment in BPC efforts is not limited to decreasing funding for DEI programs. Even if CS departments maintain funding for those programs, the administrators and faculty leading BPC efforts may have decreased bandwidth to support them. Facing pressures to teach more courses, lab sections, and students may constrain faculty members' time, such that it becomes increasingly difficult for them to coordinate DEI programming. For those same reasons, CS departments may have difficulty prioritizing reforms to the CS curriculum (Strategy 1) or recruiting a team to spearhead the development, implementation, and evaluation of those structural changes.

4.1.4 Managing Enrollment Demand and BPC Efforts

Momentum conducted a study to capture the perspectives of computing departments on BPC efforts during the undergraduate CS enrollment boom [66]. Interviews with 55 stakeholders across four public U.S. universities reveal that schools are not factoring DEI and BPC considerations into their decisions for managing growing CS enrollments. Momentum's research shows that CS departments broadly do not view managing the enrollment boom and advancing BPC initiatives as "mutually informing" areas of need. As outlined here and summarized by

Momentum, "the ability to think through how these priorities are interwoven, and narrate them in relation to each other, is a necessary precursor to equitable decision making" [66]. Without understanding the intertwined nature of these two issues, institutional responses to increased enrollment demand are likely to hinder, if not counteract, efforts to increase gender equity in CS.

While unprecedented enrollment demand poses resourcing challenges for CS departments, the Momentum study provides an important reminder that CS departments—along with their students—are constantly affected by outside forces [66]. For example, the COVID-19 pandemic provoked significant changes to how educational institutions operate and provide instruction [71], with CS departments as no exception [72]. The move to "emergency remote teaching" as university facilities shut down during COVID-19 highlighted economic and infrastructural disparities faced by students. Schools not only had to adapt quickly, mid-semester to a fully remote teaching model but also had to account for the fact that their students (and sometimes faculty) were distributed across disparate learning environments, some of which lacked consistent internet access and hardware particularly important for CS coursework. While interviews with university CS practitioners about the shift to remote teaching reveal a variety of views on its successes and drawbacks, concerns about equitable access to technology were a common theme [72].

There is no limit to the external factors that might impose constraints on a university or department's resources, and these forces will often have a disproportionate impact on students who are already disadvantaged or excluded. If CS departments continually deprioritize BPC efforts in reaction to these external factors, the current culture and demographics of CS will never change. Instead, schools must rethink their approaches to addressing these external forces, such as rapid enrollment growth, not only to accommodate but to prioritize persistent support for BPC.

4.2 Barrier 2: Lack of Incentives for Structural Change

While colleges and universities face resource constraints that may make it challenging to prioritize BPC efforts, the past three decades that researchers have spent examining DEI issues in CS have produced no lack of guidance or funding to advance these initiatives. Literature abounds on the reasons that CS education lacks representation of women and other marginalized identities [5-7, 12, 33-34, 40-41, 43, 73] and the measures for increasing that representation [8-9, 18, 44-51]. As of 2014, the NSF stated that it had dedicated over $110 million to funding BPC efforts over the past several years alone [74]. Some of this funding contributed to institutions like BRAID that partnered with dozens of universities to implement structural changes to their CS departments [61]. CIC continues to partner with dozens of schools, offering two types of grants geared towards increasing the representation of women in CS [64].

It seems that, despite the past **30 years' worth** of resources and approaches dedicated to addressing gender equity issues in computing education, CS departments lack incentives to genuinely embrace structural change. At the surface-level, undergraduate CS departments are producing CS graduates at a rapidly increasing rate to satisfy an increasing demand by employers for CS candidates. If the primary goal of CS departments is to provide CS majors with a strong foundation in computing to prepare them for the transition into the CS workforce, then departments may view their current strategies and curricular structure as successful for achieving that goal.

However, that goal is incomplete and short-sighted. Who is that CS education accessible to? Does it produce a diverse pool of CS graduates, who bring a wide range of perspectives to CS and engineering roles? Does it prepare students who are underrepresented in computing to confidently transition into the CS workforce, where women experience low rates of persistence [75]? If CS departments fail to account for these questions when defining their objectives and success metrics, then departments may lack motivation to pursue BPC measures in earnest.

The longitudinal study of BRAID schools conducted by Momentum provides insight into some limitations of CS departments' sincere commitment to BPC. Part of that study—focused on BPC leadership by department chairs—reveals that, though "few departments came to the BRAID initiative with specific goals" for increasing the participation of women and other underrepresented students, "many of them joined the project with a general commitment" and struggled to identify the point at which they could declare success for their efforts [76]. While establishing concrete goals and success metrics for BPC is important for tracking progress, the nature of equity work is one of continuous improvement. Initial progress in advancing gender equity requires a high degree of energy and time—what took HMC [11] and CMU [8] five years to achieve took nearly 10 years for Northwestern [49] and may take longer for other schools. Even nearing or attaining gender parity, HMC and CMU have not only maintained that progress but continued to evolve their goals and efforts over time [18, 47].

In addition to the difficulty departments demonstrated in defining clear objectives for their BPC efforts, the Momentum study also shows that CS departments often struggle to equitably distribute and reward BPC work. According to Momentum, in nearly all departments studied, a "small group of dedicated faculty and students" were responsible for the lion's share of effort to "create a more welcoming and inclusive departmental culture" [76]. While these BPC leaders "did not generally face opposition" from the rest of the CS department, they rarely received the resources needed to support their level of effort. Interviews with department chairs communicated a general view of "diversity initiatives as something that faculty members [are] personally interested in" rather than important work on behalf of the department that warrants "course relief or compensation." This characterization demonstrates a lack of value placed on BPC efforts and their leaders, along with a reluctance to assume institutional responsibility for equity issues in CS education.

Further, this reveals that the appearance of actively engaging with BPC research and initiatives does not necessarily indicate that schools are taking equity-enhancing measures to heart. As previously stated, gender equity in CS education is a *structural* issue, which requires *institutional*, and not just *individual*, effort to address. As explained by Maria Klawe, leader of HMC's BPC efforts, "the truth is that every CS department that has made a serious and sustained commitment to increasing female participation," leveraging any and all of the strategies outlined here, "has had substantial success" [11]. In contrast, approaching BPC efforts without a genuine commitment to DEI or without incentivizing buy-in from the entire department, leads to performative or under-supported actions that lack results.

As assessed by NASEM: "It is a time for institutions to consider their missions and the constituencies they serve, and to determine what role computing should play in the experience, knowledge, and skills of its graduates" [69]. If CS educators and institutions are not aligning their goals to meet the aims and needs of the constituencies they serve—and, perhaps more importantly, those they fail to serve—then the amount of funding and research going into BPC efforts will not matter. While advancing gender equity in CS education is a nuanced and challenging problem, CS departments have the tools and strategies needed to make progress; now, it is time to use them.

5 Recommendations

Though this analysis focuses on efforts to increase gender equity in undergraduate CS education, the impact of those efforts extends well beyond academia. In addition to shaping the demographics and culture of the CS classroom, BPC initiatives shape the CS candidate pool for government and industry employers. When effective, these efforts serve to diversify and enhance that candidate pool—not only increasing the proportion of women and other underrepresented students but, hopefully, boosting their confidence in their CS abilities and sense of belonging in the field. This means that employers who value DEI and understand its importance to the creation of equitable, effective technologies also have a stake in the success of BPC efforts.

Thus, the following section outlines actionable recommendations for three primary stakeholder groups—academia, industry, and government—to support the advancement of gender equity in undergraduate CS education. These institution groups possess the power to influence and institute structural changes to CS education that, by making the field more welcoming to a diversity of backgrounds and perspectives, better enable inclusive and responsible technological innovation.

5.1 For Academia

Having already covered the strategies that have proven successful for academic institutions in addressing this issue, along with the barriers that can inhibit their success, the recommendations for academia are relatively straightforward. Structural changes to both the curriculum and culture of CS education are key to increasing the representation of women—understanding that universities may require time to plan and allocate resources for these changes. Due to those constraints, it is vital that schools actively prioritize BPC efforts, demonstrating their commitment by implementing consistent, if relatively small, changes that align to the strategies for increasing gender equity in CS.

The objective of this section is not to provide an exhaustive list of such changes but rather to offer some examples of how to adapt or scale the core strategies to suit an institution's particular context. These examples include potential changes to a school's CS department, as well as alternative options that support more inclusive computing outside of the traditional CS department.

5.1.1 Recommendation 1: Increase Interdisciplinary Programming (Within the CS Department)

The crux of reforming the CS curriculum, as proposed here, is shifting the focus from demonstrating technical excellence to applying CS competencies to solve real-world problems. Infusing CS education with that context often requires partnering with and incorporating other disciplines, such as psychology, biology, or media studies. There are various methods of creating or increasing interdisciplinary programming in CS, starting with the development of cross-disciplinary courses or programs that facilitate collaboration between CS and other departments. One approach is the "threads" model offered by the Georgia Institute of Technology (Georgia Tech), which enables CS majors to select two "threads" or tracks of courses that apply computing to specific areas of interest [77]. Georgia Tech offers eight of these "threads," some of which (Devices, Systems & Architecture, Theory) align more with traditional CS curricula, while others (Media, Intelligence, People) expand the curriculum to include classes in other departments, such as psychology. This method not only centers the curriculum around real-world applications of CS but also highlights the breadth of possible applications, allowing students to explore approaches to CS that are deeply technical, along with those that are more socially or relationally focused.

Another means of contextualizing CS without restructuring the entire curriculum is offering CS+X, or interdisciplinary degree, programs. The University of Illinois Urbana-Champaign—a current CIC partner—has introduced a series of CS+X programs that enable students to combine the core CS curriculum with one of 12 disciplines, including anthropology, chemistry, education, music, and even animal sciences [78]. MIT has introduced three interdisciplinary CS degrees, combining CS with cognition, molecular biology, and economics [79]. According to NASEM [69], given that many of the disciplines paired with CS through these programs have higher gender parity and overall diversity, these "blends" can be "effective at improving the diversity of computing-related programs, even if they are not housed in CS units." One caveat to this approach is the importance of creating programs that truly integrate the disciplines which they seek to combine, rather than simply doubling students' course requirements. After piloting a CS+X Joint Major Program (JMP) led by the Schools of Engineering and Humanities and Sciences for several years, Stanford University discontinued the JMP in 2019, due to its "burdensome" requirements [80]. Given the time-intensive nature of many CS programs, schools should craft their interdisciplinary programs with curricular flexibility and cohesion in mind.

While supporting BPC initiatives by providing some adaptations to the traditional CS curriculum, these efforts can also help CS departments meet increasing enrollment demand by engaging CS students with faculty and courses from other departments. Whether simply decreasing the number of courses students are required to take within the CS department or bringing in faculty from other departments to teach cross-disciplinary courses, increasing the interdisciplinary nature of CS may help to mitigate issues with hiring enough CS faculty. Additionally, CS departments can also offer training to graduate students and faculty from other disciplines to increase the number of CS instructors. As framed by NASEM [69], "teaching computing outside of CS would also seem to offer institutions more flexibility if there are significant fluctuations in student demand in the future," making this a sustainable option for balancing enrollment demand with BPC initiatives.

5.1.2 Recommendation 2: Create New Pathways for Computing (Outside of the CS Department)

Schools whose CS departments are unable or unwilling to embrace these structural changes, at any level of implementation, should consider developing new computing programs outside of the CS department. The University of Michigan recently announced the Program in Computing for the Arts and Sciences (PCAS), an interdisciplinary CS major housed in the school's College of Literature, Sciences, and the Arts (LSA) [81]. While the university already offers two CS degree programs—a B.S. in the College of Engineering and B.A. in LSA—this new program aims to equip students with foundational CS skills for application to focus areas in the sciences and humanities, such as discovery, justice, or creative expression. This major is the result of an assessment of computing education in LSA commissioned by the dean of LSA in the fall of 2020. The LSA Computing Education Task Force's report [82] called for the department to take more ownership of computational and digital (C&D) education and to develop additional C&D degree pathways.

The report cites that, for one semester, the CS department in the College of Engineering offered an introductory course geared towards non-majors focused on "the fundamentals of computer science and its impact on people, society, and innovation" [82]. Despite the course's popularity, the department retired it and reassigned the professor to teach upper-level CS courses due to the “exploding number of CS majors.” Given the resource constraints of the school’s CS departments and the significantly higher representation of women and students of color in LSA overall, the task force determined that LSA should create another, nontraditional computing program to capture the context and attract the student populations that the other programs were missing. While it is too soon to assess the impact of PCAS, its goals and structure seem well-aligned with the core strategies for increasing gender equity in computing education.

5.1.3 Case By Case

The cases of CMU and HMC illustrate the power of introducing broad, sweeping changes to achieve significant increases in gender equity over a short period. While it is crucial to realize that level of success is possible, it is also important to acknowledge that it may not be immediately feasible for all schools to emulate. Others may need to institute incremental changes to their CS departments or work towards building entirely new structures for computing education in order to effectively advance BPC efforts.

Ultimately, this research—conducted from a standpoint outside of academia—cannot identify the best approach for schools to address issues of gender equity in CS education; individual colleges and universities must make that determination for themselves. What it can do is offer a survey of the strategies and methods that have helped schools increase DEI in CS, along with the encouragement for computing departments to accept responsibility for BPC and actively research, institute, and evaluate measures to advance gender equity.

5.2 For MITRE and Other Industry

As stated earlier, employers and industry partners also have a role to play in advancing gender equity in CS education—shaping the development of a more diverse and representative workforce. This research aims to provide industry with greater insight into current inequities in CS education, as well as the potential impact of those inequities on CS workers and the technologies they create. That perspective should inform not only the partnerships that CS employers create with academic institutions but also the ways in which companies evaluate equity within their own CS workforce.

5.2.1 Recommendation 1: Factor BPC Efforts Into Academic Partnerships

With a deeper understanding the strategies available to academic institutions for increasing gender equity in CS, employers can take a schools’ demonstrated commitment to BPC into account when forming academic partnerships. If building a diverse and inclusive workforce is important to industry employers, they can communicate those expectations to academic partners and seek to establish hiring pipelines with colleges and universities that produce more diverse candidate pools or are actively instituting changes to increase DEI in CS. Expressing a demand to bring candidates of diverse backgrounds and perspectives into the CS workforce—so long as that demand is backed by recruitment and outreach practices that prioritize partnerships with schools who meet it—can create additional incentives for CS departments to embrace structural changes, reducing the barriers to their success.

Industry employers should also consider more actively incorporating nontraditional computing programs, like PCAS and CS+X programs, into their hiring pipelines. While these programs likely vary in how technical they are, employers can evaluate the degree to which a program’s foundational requirements for CS meet their qualifications. Outreach to nontraditional computing programs of interest is particularly important, given that students from outside traditional CS majors may feel intimidated in applying to technical CS roles, even if they have the skills needed to succeed. Recruiting from these alternative computing programs, targeted at students excluded from traditional CS, likely provides employers with access to a greater diversity of candidates. It also reinforces the message to schools that their CS departments must prioritize BPC efforts and evolve in order to stay competitive.

5.2.2 Recommendation 2: Assess Gender Equity Within the CS Workforce

Outside of recruitment, industry also stands to benefit by applying the core strategies proven successful for increasing gender equity in academia to their own structures and frameworks. The field of CS has a gender equity problem that extends well beyond undergraduate education—reaching back into primary and secondary education and on into representation and retention in the workforce. Advancing progress made at the level of undergraduate CS education requires applying a critical lens to industry practices that might otherwise undermine it.

One way for organizations to invest in BPC efforts of their own is by evaluating any internal or external CS training opportunities they provide to their employees against the core strategies for increasing equity to identify areas of improvement. Industry employers want to avoid reinforcing exclusionary elements of the prevailing CS culture through their training programs, so as not to derail positive cultural changes made in academia or disillusion the workforce they are actively working to diversify. Further, organizations employing CS workers should regularly collect, analyze, and share data on what identities (based on gender, race and ethnicity, ability, etc.) are represented within their CS workforce, particularly in technical roles. These metrics should be granular enough to be useful, such that they enable stakeholders to identify specific subsectors of the company's CS workforce (for instance, software development or system architecture) that show greater disparities or require more BPC investment.

Adopting a similar focus on methods for BPC enables industry not only to support but to amplify efforts in academia for advancing gender equity in CS education. Doing so also allows organizations to stake a claim in the future of the CS workforce and shape it to better serve their objectives.

5.3 For Government

While the recommendations for industry also apply to government organizations that employ CS workers or support CS education, government stakeholders have additional measures at their disposal to address gender inequity in CS education. Given the variety of tools available to different government agencies—research, policymaking and implementation, grantmaking, and so on—the following recommendations are far from exhaustive. They highlight actions and focus areas that align with those identified for the other stakeholder groups to encourage a coordinated approach to the issue by all stakeholders. That said, the most important takeaway for government stakeholders is an increased awareness of current inequities in CS education. With that, individual agencies can make an informed assessment of which tools and approaches best serve their aims for advancing gender equity in CS.

5.3.1 Recommendation 1: Develop Mechanisms for Incentivizing BPC Efforts

Agencies that heavily recruit CS majors may rely on scholarship programs, such as the Scholarships for Service offered through CyberCorps [83], to attract technical talent. Forging partnerships under those scholarship programs with computing programs that prioritize BPC creates a strong incentive for schools to implement BPC measures. Again, many of the structural changes to CS advocated by the core strategies shift from a strictly technical to a more contextual approach to the discipline. This shift plays to the favor of government agencies. Academic programs that are grounded in real-world—especially service-oriented—applications of CS are not only likely to produce a more diverse pool of applicants but also likely more aligned pedagogically with the public service mission of government stakeholders. Thus, reshaping these scholarship programs to emphasize BPC incentivizes changes to CS education that should yield a return on the agencies' investment.

In addition to recruiting graduates from CS programs that demonstrate a strong commitment to BPC, government stakeholders can form other kinds of partnerships that incentivize schools' investment in equity-enhancing changes to computing education. Agencies can establish grants to help fund structural changes to university CS programs, providing incentives and support not only for BPC research but for the implementation of strategies revealed through that research. Instead of developing their own funding programs, government stakeholders can also partner with existing organizations like CIC to encourage the adoption of proven measures for BPC.

5.3.2 Recommendation 2: Evaluate Gender Equity in Internal CS Training Programs

While evaluating an organization's training programs against the core strategies is important for industry stakeholders as well, this is particularly important for government stakeholders who recruit workers into CS roles from nontraditional backgrounds. Specifically, this includes defense organizations that provide training and skilling opportunities to active or former military members, recruiting them to CS work without requiring a formal degree. In these cases, internal training programs designed to increase the technical workforce by upskilling current talent, may serve as trainees' first exposure to CS. As with academic CS education, it is important that those skilling opportunities are accessible to and inclusive of a diverse class of trainees. Government stakeholders who operate such training programs should assess the culture of CS within their organizations and consider which elements of the core strategies might increase the equity and inclusivity of their programming. When it comes to internally cultivating a technical cadre, departments and agencies have the ultimate influence over—and, therefore, responsibility for—the factors determining who is represented and accepted within that workforce.

6 Conclusion

The underrepresentation of women in undergraduate CS education is a persistent—but not unsolvable—problem. Analyzing the models of CMU, HMC, and other analogs reveals five core strategies for increasing gender equity and women's representation in CS:

1. Reform computer science curriculum.
2. Encourage inclusive classroom dynamics.
3. Increase institutional and classroom support.
4. Provide opportunities to gain practical experience and exposure.

5. Create and promote a sense of community.

Each of these strategies directly addresses the factors limiting women's participation in CS education, serving to mitigate the gender experience and confidence gaps, reshape the curriculum to appeal to a broader array of interests, and disrupt discouraging stereotypes about and elements of computing culture. Together, these structural changes to CS education help to increase female students' sense of belonging in the field, laying the foundation for increases in representation.

Recognizing that colleges and universities face barriers to the successful implementation of these strategies—namely resource constraints caused by unprecedented enrollment demand and a lack of incentives to undertake structural change—this paper provides suggestions for overcoming those barriers to propel BPC efforts forward. For industry and government stakeholders who also have a vested interest in diversification of the CS workforce, there are actionable recommendations for supporting the BPC work of academic partners and adapting relevant strategies to advance gender equity within their own organizations.

Sincere commitment, prioritization, and consistent support from all stakeholders can transform undergraduate CS education, enhancing equity and inclusion for women and other underrepresented student groups on the national scale. These actions have a ripple effect; dedicating resources to increase diversity in undergraduate CS education impacts the pool of candidates (and, thus, backgrounds, experiences, and perspectives) entering the CS workforce, which shapes the future of technological innovation—hopefully, in a direction more ethical, equitable, and representative of all.

6.1.1 Limitations and Implications for Future Work

While this research provides a basic framework for analyzing and addressing gender inequities in undergraduate CS education, there are many facets of this issue that merit further exploration. For one, undergraduate programs are only one component of the educational pipeline. There is a significant body of research on gender in secondary CS education, and the cases of CMU and HMC provide additional strategies for outreach to high school CS programs [8, 11]. The core strategies identified here do not address university recruitment and outreach efforts, given the focus of this paper on structural changes to collegiate CS curricula and culture. As explained by Lecia Barker, professor and researcher on equity in computing, "recruitment efforts may be a poor investment of scarce resources without simultaneously considering retention" [9]. While CS educators should not increase focus on recruitment and outreach in lieu of implementing structural reforms to their CS programs, coupling the two efforts could amplify the impact on equity in computing.

Further, the scope of this analysis is limited to bachelor's degree programs at four-year U.S. colleges and universities. Comparison to CS degree programs at international academic institutions may reveal other factors or strategies for increasing gender equity in CS. Analysis of the demographics, culture, and curriculum of two-year associate's programs may also yield additional insights, especially given indications from "Inside the Double Bind" that these programs typically have higher racial, ethnic, and socioeconomic diversity [40]. Similar research reveals that the culture of computing may differ at Historically Black Colleges and Universities (HBCUs), with greater emphasis placed on community and collaborative success over individual student achievement [43, 84]. Given that the case studies examined here are co-ed PWIs, studying CS programs at institutions designed to serve the demographics of students who are currently underrepresented in undergraduate CS—HBCUs, Hispanic Serving Institutions (HSIs), Tribal Colleges and Universities (TCUs), and women's colleges—would enhance the core strategies, increasing their inclusivity.

Though this paper provides some commentary on the intersection of gender, race, and ethnicity in relation to women's experiences in CS education, the synthesis from "Inside the Double Bind" reveals that there is limited literature available focused specifically on the experiences of women of color in CS [40]. More research centering the experiences of women of color in CS education is needed to ensure that structural changes to CS increase equity for all women—not just White women. In a similar vein, while this analysis touches lightly upon the links between class and access to CS, the socioeconomic disparities in CS education warrant much deeper investigation. Finally, as stated at the start, the data analyzed here captures a binary, and thus incomplete, depiction of gender representation in CS. In order to fully understand and combat gender inequities in CS education, it is important to research the experiences of students of all genders, including nonbinary students and transgender students who are not accurately represented in the current data. Focusing future efforts on more intersectional research can only continue to improve the core strategies outlined here, making CS education more equitable for everyone.

7 References

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Appendix A Abbreviations and Acronyms

Term	Definition
ACM-W	Association for Computing Machinery - Women
ARTSI	Advancing Robotics Technology for Social Impact
BASIC	Beginner's All-Purpose Symbolic Instruction Code
BPC	Broadening Participation in Computing
BRAID	Building, Recruiting, And Inclusion for Diversity
C&D	Computational & Digital
CIC	Center for Inclusive Computing
CMU	Carnegie Mellon University
CS	Computer Science
DEI	Diversity, Equity, and Inclusion
GA	Gendered Attrition
Georgia Tech	Georgia Institute of Technology
GHC	Grace Hopper Celebration of Women in Computing
HBCU	Historically Black College or University
HMC	Harvey Mudd College
HSI	Hispanic Serving Institution
JMP	Joint Major Program
LSA	College of Literature, Sciences, and the Arts
NASEM	National Academies of Sciences, Engineering, and Medicine
NCES	National Center for Education Statistics
NCWIT	National Center for Women & Information Technology
NSF	National Science Foundation
PCAS	Program in Computing for the Arts and Sciences
PWI	Predominately White Institution
STEM	Science, Technology, Engineering, and Mathematics
TCU	Tribal College or University
UBC	University of British Columbia
Women@SCS	Women in the School of Computer Science