Bridging the Gender Gap in Undergraduate Computing Programs: A Sociotechnical Approach

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by

Jonathan Gordon

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Jonathan Gordon

Sociotechnical advisor: Peter Norton, Department of Engineering and Society

Introduction

Computer science is one of the fastest-growing and most lucrative fields of employment. In the United States, the median pay for a computer industry professional was $122,840 in 2019, and the Bureau of Labor Statistics (2020) predicts an industry growth of 15 percent in the next decade. However, data from K-12 education and university program enrollment in computing studies shows clearly that computer science is a male-dominated field. According to data from College Board (2020), of the 70,580 students who took the 2020 AP Computer Science A exam, only 25 percent were female. Moreover, despite there being significantly more female students taking AP exams than male students - nearly 1.5 million versus 1.1 million, respectively - the proportion of male AP students taking the AP Computer Science A exam outnumbered the proportion of female AP students by a factor of 4 (College Board, 2020).

This gender discrepancy in computing studies continues into university and beyond. In a 2017 survey of Ph.D. awarding institutions, the Computing Research Association reported that introductory courses for computing majors at public universities had a median female enrollment of 21 percent; for upper level computing courses, this figure drops to 15 percent. The National Science Foundation (2015) reports that only 18 percent of all computer science bachelor's degrees awarded are earned by women. Interestingly, this phenomenon of low female participation in computing studies does not extend to other STEM fields. The share of computer science bachelor's degrees awarded to women has declined from 27 percent in 2000, despite increases in numbers of science and engineering degrees awarded to women in the same period (NSF, 2015). In one study, over 77 percent of women (compared to 45 percent of men) who initially declared a computer science major eventually left STEM altogether, the highest rate of any STEM field (Ferrare & Lee, 2014).

The gender gap in computing is disadvantageous in many ways. For female computing professionals, lower representation in the workplace can lead to feelings of discomfort and gender-related discrimination. According to Pew Research Center (2018), over half of women working in STEM had experienced some form of gender-related discrimination at work. For women not already in the industry, there may be the appearance of an exclusionary culture that results in lower participation in the field. For example, one study of university recruiting sessions found that tech companies often cater to a male audience, alienating and lessening the interest of female computing students through gendered references, overt stereotyping, and gender-imbalanced presenter roles (Wynn & Correll, 2018). Tech companies suffer too as a result of lower diversity, which has been shown to improve company performance and innovation (Dai, Byun, & Ding, 2019).

Though a deficit of women in tech harms everyone in an increasingly technological world, school districts have not made computer science education a priority beyond offering elective classes, which predominantly enroll male students over female students (Blikstein, 2018). Instead, the primary groups making attempts to solve this problem are independent organizations and universities. Many independent organizations have attempted to address the gender gap by offering programming courses or camps for young girls, citing lack of prior exposure as a reason for low interest in computing. For example, Girls Who Code contends that girls need extracurricular opportunities until school boards make computing education mandatory for all students. Some undergraduate educational institutions, such as Harvey Mudd College and UC Berkeley, have revamped their computer science curricula, claiming that most computing courses are not delivered in a way that connects with female students' ideals. The most effective measures to close the gender gap in computing approach the problem from a sociotechnical perspective: they acknowledge a variety of social factors that inhibit women from engaging with technology, and give them agency to overcome these factors and develop an identity as technologists.

Review of Research

Alshahrani et al. (2018) found that discrepancies between men and women choosing to study computing may be heavily influenced by a lack of prior experience, social support, self-efficacy, or outcome expectations in women. They cite Taylor and Mounfield (1994), who found that prior experience in computing strongly correlates with female undergraduate success in a computer science major. Given the overwhelmingly male makeup of high school computing courses, women may simply not have enough exposure to the subject to choose it as a field of study. Insufficient exposure may limit self-perceptions of computing skill and amplify feelings of low confidence and self-efficacy in women (He & Freeman, 2010). However, even when women performed equally to men in computing tasks, they indicated lower levels of confidence in self-assessments (Liberatore & Wagner, 2020). This is significant, Alshahrani et al. (2018) point out, as "most people are attracted to, and pursue, tasks and fields in which they are confident."

Some researchers consider social attitudes towards computer science the culprit. Cheryan et al. (2013) found that perceptions of computer science as "nerdy," with little social connection, deters women from computer science more than men. Cheryan et al. (2013) argue that stereotypical impressions of computer scientists as "lacking interpersonal skills and being singularly focused on computers" are "incompatible with the female gender role." Blaney and Stout (2017) found that women rated their self-efficacy and sense of belonging in computing significantly lower than men (especially so among first-generation college groups). Even when controlling for self-efficacy, a sense of belonging is a powerful predictor of academic persistence in STEM fields (Lewis et al., 2017).

Sense of belonging can be better understood as an influence toward continued academic persistence in computing from the perspective of the Social Construction of Technology (SCOT) framework. SCOT, developed by Pinch and Bijker in 1984, asserts that various social groups have unique values regarding particular technologies, or "interpretive flexibility." Furthermore, it is a result of these social groups' relationships with a particular technology that allows that technology to reach a stable state, or "closure." Given the historical absence of women in computing, it may be that computer science as a culture has reached such closure, without the contribution of women as a relevant social group. Garcia and Scott (2016) explore these ideas by applying the lens of intersectional feminist science to SCOT, examining efforts to increase the number of women of color in STEM fields, and how they have fallen short due to their focus on technical acuity and general disregard for the social relationship between technology and its users. Garcia and Scott argue that emphasizing interpretive flexibility should be a primary focus of computing education outreach programs for women and girls.

Youth Outreach

Several nonprofits offer technology outreach programs for middle and high school girls, either teaching the basics of coding through fun projects, or simply forming a club around a shared interest in computing. The intention of these programs is not necessarily to teach computer science, but rather to create an exposure for young women, introducing technology as something to interact with and control as opposed to something that is merely observed and experienced. A degree of prior exposure will hopefully improve girls' level of interest in computing and lead to higher retention rates in university and beyond, as suggested by Taylor and Mounfield (1994).

For example, Girls Who Code is a national nonprofit that organizes and supports outreach programs and after-school clubs for elementary to high school girls. Their flagship extracurricular activity is the Summer Immersion Program (SIP), a free two-week summer camp for high school girls to learn and practice HTML, CSS, and JavaScript. Program participants are assumed to have little to no experience in computing. They are taught via traditional lecture for two hours each day, and spend the rest of their time working independently or collaboratively on personal projects, as well as attending events and seminars by female role models in the field. Outcomes for SIP participants seem to indicate that such an experience can lead to higher interest and retention rates for women in computing: alumni go on to major in computer science and related fields at an astonishing 15 times the national average (Girls Who Code, 2019).

However, a two-week summer coding program may self-select for girls already interested or experienced in computing, without reaching girls who feel no belonging in the field. Hosting a free summer camp for interested teens is not all that different from offering AP CS as a school elective, which has already been shown to attract boys over girls by a margin of three to one (College Board, 2020). Reshma Saujani, the founder of Girls Who Code, responds to this criticism by proposing that states make computer science education mandatory for all students. Growing up with an equal amount of exposure to computing will even the playing field, and stop a self-perpetuating cycle of girls filtering themselves out of a field that is perceived as “full of dudes,” she says (Blanding, 2018).

Craig and Horton (2009) caution that a long summer camp would not appeal to “mathematically-competent girls who were self-selecting out of CS.” They experimented with a one-day program—offered as an alternative to school that day—which introduced girls to CS and CS careers. The program content emphasized creativity, design, and accessibility. Girls were not given formal instruction on coding languages or theory. Instead, girls explored human-computer interaction by designing their own interfaces, learned about sequential execution by filling out programming “mad-libs,” and created their own animations using the educational programming language Scratch. A pre-survey showed that program attendees were not especially interested in pursuing computing academically or as a career - it ranked 6th among 11 career choices for being “cool/interesting,” and 7th in “likelihood to pursue as a career.” At the end of the program, computing rose to 2nd place in each category, owing to over 50% of respondents increasing their score. Furthermore, many of the respondents who indicated that it was very unlikely they would pursue computing as a career in the pre-survey had much higher interest at the end of the program, suggesting that the program was effective at reaching girls who did not see themselves as computer scientists. In a follow-up survey conducted three months later, the positive effects from the program persisted (Craig & Horton, 2009).

The results of youth outreach programs like Girls Who Code’s SIP show that opportunities to expose girls to the ins and outs of computing can have a massive positive impact on academic and career interest in the field. However, programs need to be careful not to replicate existing paradigms of catering to those who are already technologically involved. This could have an effect of perpetuating a cycle of girls who pass up such opportunities because they see computing as something that is not for them. Craig and Horton’s experiment with a one-day program shows that taking a broad, accessible approach - especially one that emphasizes creativity and expression over technicality - can have a positive influence on girls who, as they put it, “self-select out of CS.”

Revamping Higher Education Curricula

Interventions at the university level may be sufficient to change attitudes about computer science and inspire female enrollment. Despite a heavy gender imbalance already existing in the field by this stage, it is also true that the majority of new undergraduates are either undecided about their major or will change their major at least once before graduating (Gordon, 1995). If universities make efforts to portray computer science in a new light that combats gendered misconceptions, the field may become more enticing to women early in their undergraduate studies. A 2009 survey of college-bound high school students found that when asked about computing, males were more likely to use words such as "video games," "design", "solving problems," and "interesting," whereas females used the words "typing," "math," "boredom," "hard," and "nerd." Perhaps unsurprisingly, male students rated computer science to be a "good" choice of major at much higher rates than female students: 74 percent to 32 percent, respectively. The researchers also found that males and females had different values when it came to career choices. Female students were significantly more likely than male students to rate "being passionate about your job" and "having the power to do good and doing work that makes a difference" as "extremely important"; males were typically more concerned with "earning a high salary" and "having the power to create and discover new things." (ACM & WGBH Education Foundation, 2009).

Professor Dan Garcia at UC Berkeley consulted the 2009 ACM-WGBH report and made significant strides in changing student perceptions in his introductory computing course "The Beauty and Joy of Computing." Previously known as "Introduction to Symbolic Programming," the course was redesigned in 2010 in such a way that "everything that turn[ed] women off, we reversed it" (Brown, 2014). Garcia explains that the philosophy of his course emphasizes exploration and having fun, approaching computer science basics with less of a focus on theory and "formality" (Garcia, Harvey, & Barnes, 2015). Pair programming is a core activity throughout the course, and students often direct their learning at their own pace in guided lab exercises. He also encourages students to consider the worldly relevance of computing, discussing a different tech news article at the beginning of every class and debating the pros and cons of various technologies. Interviews show that Garcia's course successfully changed student perceptions of computer science, and that the course's creative curriculum may connect better with "the female gender role" as alluded to in Cheryan et al. (2013). One student questioned her opinion about programming as "boring lines of code everywhere" based on the course title; and had so much fun during the course that she joined the electrical engineering and computer science major. Quantitatively, the effects of this course revamp speak for themselves: from 2009 to 2013 the number of female computer science majors nearly doubled, and in the spring 2013 semester, female students enrolled in the course outnumbered male students (Brown, 2014).

Other successful efforts at the university level have focused on creating a more social environment among students, as well as increasing connections between female students and the computing community. Harvey Mudd College (HMC), for instance, changed their curriculum in 2006 to offer more team-based projects and pair programming opportunities in introductory computing courses. They also began taking some first-year women to the Grace Hopper Celebration for Women in Computing, an annual conference of women in or related to the computing community. Lastly, more research opportunities were made available to women with little computing experience (one or two semesters of computer science courses taken). Within four years of these changes being implemented, the proportion of women in the computer science major at HMC increased from 10 percent to 40 percent. Over 70 percent of these women pointed to the CS1 course as a reason for their choice of major (compared to 55 percent of men), and over 60 percent of women indicated their interactions with CS professors as an additional reason (compared to 30 percent of men). Strikingly, over 40 percent of women computing majors reported a research experience after their freshman year as influential to their choice of major, compared to just 10 percent of men (Alvarado & Dodds, 2010).

Like Professor Garcia at Berkeley, HMC modified their computing curriculum to create a more positive experience for women, only in a different way. Professor Garcia appealed to a sense of worldliness in female students - alluded to in the ACM-WGBH study - by making his course less theoretical and more concerned with the impact of computing in the real world. HMC's curriculum revamp, on the other hand, emphasized social connection, including team-based assignments in intro courses and lowering barriers to connect with an influential professional community. Drastically improved outcomes in both examples, however, demonstrate that universities can make a significant impact on the gender problem in computing by understanding the social factors that inhibit women from studying computer science: namely that women as a social group have different values from men, and computer science education by and large is not geared towards them.

Focus on Interpretive Flexibility

Pinch and Bijker's definitions of "interpretive flexibility" and "closure" give a sociotechnical lens through which we can understand the gender gap in computing, and evaluate efforts to ameliorate it. Garcia and Scott (2016) use these definitions to explain their position that technology is a socially-shaped and open process, but stress that underrepresented groups in computing (namely women of color) have had extremely little influence in its social development, effectively becoming "victims" of technology. They criticize many outreach programs for "simplify[ing] the complex problem of disparity in technological initiatives as mainly a 'computing skills' problem," and employing an "add girls, sprinkle a programming language, and stir" methodology. Garcia and Scott argue that efforts to retain women of color in computing should rehabilitate the interpretive flexibility of the group, and provide women of color with an alternative social relationship with technology where they can be agents instead of victims.

Their primary example is CompuGirls, a "culturally relevant" technology program that teaches girls of color from under-resourced schools how to use technology to approach their intersectional identities, and critically examine technology as a socially shaped artifact. In the program, girls use the educational programming language Scratch to create visual representations of societal stereotypes of women of color, as well as positive representations of how they see themselves. They are then asked to discuss what social forces have an interest in spreading negative images of women of color. Furthermore, girls are asked to identify any limitations with the technology in regards to authentically representing themselves. This program makes an effort to stress the interpretive flexibility of technology, asking participants to think critically about how technology is socially constructed by a group of people for a group of people, and how it can be changed by a social group acting as agents (Garcia & Scott, 2016).

Women and other underrepresented groups tend to rate their sense of belonging in computing relatively low (Blaney & Stout, 2017). Participants in CompuGirls indicated that perceptions of STEM culture as antagonistic toward women of color impacted their sense of belonging in the field. However, taking up an agentic role and critically examining computing from a sociotechnical perspective had a positive influence on participants' perceptions as well as identities as they relate to technology (Scott & White, 2013). By addressing social factors that inhibit women of color, and emphasizing interpretive flexibility with regard to technology, CompuGirls positively impacted girls' sense of belonging, a key indicator of academic persistence.

Few efforts to close the gender gap in computing ask women to critically examine technology from the perspective of race or gender, as CompuGirls does. But the most successful programs do recognize the social factors surrounding the problem, and focus on reshaping students' interpretive flexibility. Craig and Horton's one-day outreach program took note of young girls' desire to express themselves, and encouraged participants to engage with computing from a creative design standpoint. Harvey Mudd's course revamp sought to tackle perceptions of computer scientists as "nerdy" and "lacking interpersonal skills," and increased female participation by promoting collaboration and social connections to professionals in computing. Professor Garcia's course specifically asks students to evaluate and discuss the societal implications of computing technologies, not only connecting with a sense of worldliness that is more salient for female students, but also encouraging students to engage in sociotechnical analysis that may further develop their identities as technologists. Garcia and Scott (2016) are correct that an "add girls, sprinkle a programming language, and stir" approach is less effective than one that acknowledges sociotechnical factors and focuses on reshaping interpretive flexibility around computing.

Conclusion

Nonprofits, universities and employers are striving to reduce the gender gap in computing. More accessible CS education and early exposure can diminish the gender gap, but more is needed. Social factors that inhibit women from engaging with technology must also be addressed, including cultural misconceptions about computer scientists, perceptions of a hostile culture within the tech industry, and curricula that are simply geared more toward male students. Efforts to solve this problem should be conscious of these social factors, and not just introduce women to computing skills, but revitalize interpretive flexibility and help women reimagine their relationship with technology.

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