Women in CS: changing the women or changing the world?

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***Abstract*—This Research Full Paper provides a review of literature regarding the participation of women in Computer Science (CS) related disciplines and discusses four different categories of variables, with the goal of determining what current professors, staff, and students can do to promote the retention and inclusion of female students in CS programs.**

1) **Static attributes of female students (race, socioeconomic background, GPA, ACT/SAT score, etc).**
2) **Adjustable attributes of the female students themselves (qualities that could be changed through workshops, courses, mentoring, or other training programs).**
3) **Static attributes of the environment around female students (location of a university, number of students enrolled, etc).**
4) **Adjustable attributes of the environments around female students (aspects of a program or university like what courses are required and in what order, who is teaching, what they are teaching, how they are teaching, etc).**

We review literature that suggests departments can attempt to influence attributes of the female students themselves, like students' self efficacy, thinking habits, and academic goals, through courses and programs. We conclude that this category of variables could be split into two ill-defined subcategories. First, variables which may be ethical to adjust, like students' confidence or self efficacy. Second, variables which may be better left unchanged: we note that if interventions lead female students to be more like their male peers, we are not attaining true diversity. We discuss the implications of attempting to change female students and discuss the effectiveness of modifying environments around female students.

We take the position that the study of static attributes, whether internal or external to female students, leads to few actionable tasks. We propose that future research should look for adjustable factors that allow for professors, staff, and students to change their actions in order to increase retention rates.

I. Introduction

In the United States, women earn 59% of biology degrees and over 40% of math and statistics [25], [48], chemistry [25], law [50], and medical degrees [50]. Yet in 2017, women earned 19.1% of computer science degrees in the US [49], and as we can see in Figure 1, this percentage has fallen dramatically since the 1980s. The numbers of men earning bachelor's degrees in CS from US institutions is increasing at a greater rate than the increasing numbers of women as shown in Figure 2. For decades, researchers have been studying recruitment and retention of women and other minorities in CS, yet it is still not apparent what departments, professors,

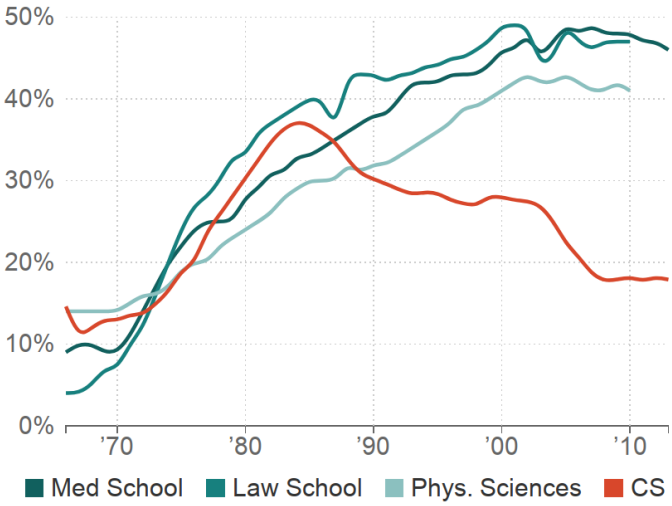

Fig. 1. Percentage of degrees awarded yearly to women in USA (graph from [50])

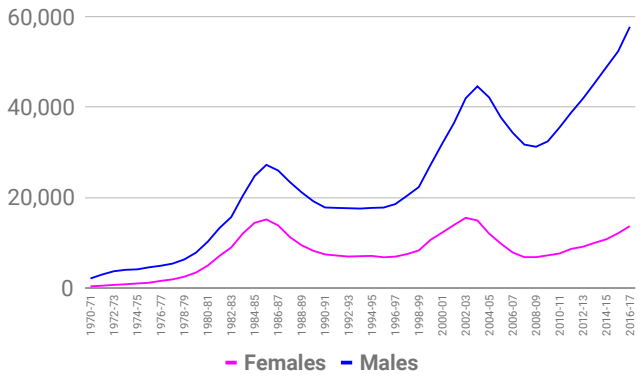

Fig. 2. Count of bachelor's degrees awarded yearly in CS in USA to men and women (data from the National Center for Education Statistics [49])

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and students can do in order to enable women to earn CS degrees.

The lack of women in CS is widespread, but is not a problem in all parts of the world. Schinzel's 1999 paper noted that industrial developed countries awarded about 20% of CS degrees to women, while undeveloped countries awarded about 50% of CS degrees to women; she discussed possible cultural and economic reasons for the correlation [60]. Similarly, Galpin's 2002 paper looked at the numbers of women in CS for different countries and found that between 10% and 40% of students or graduates in CS were female in most countries [20]. Some notable exceptions include Armenia, where for nearly 20 years the percentage of CS students who were female was above 75% [22] and Mauritius where the numbers of women in CS programs grew from 17 to 38% in the 1990's while the numbers of women in CS were falling around the globe [1].

Other papers have looked at subsets of women, like Lopez and Schulte's paper that used over a decade of information about African American students studying CS in the USA [37]. They found that Historically Black Colleges and Universities (HBCUs) awarded more CS degrees to women than they did to men, while at non-HBCUs, African American men were earning more Bachelor's degrees in CS than African American women by a slight margin. Eidelman and Hazzan noted that in Israel, 28% of CS students in the Jewish sector were female, while 61% of CS students in the Arab sector were female [17].

These differences in rates of female participation in computing between races and cultures suggest that culture can be sufficient to increase the number of women in CS.

As Frieze et al. wrote, "Gender difference approaches have not provided satisfactory explanations for the low participation of women in CS and beliefs in a gender divide may deter women from seeing themselves in male dominated fields. We strongly believe that without due caution the search for gender differences can work against diversity and inclusion efforts, while perpetuating stereotypes and further marginalizing women." [19]. It appears that there are non-biological factors, internal or external, that make women of some races, or in some cultures or countries, more interested or more successful in CS.

Research has identified several reasons women are less likely to major in computer science than men. The K-12 educational system is often referred to as a "leaky pipeline" because with each additional year of schooling, fewer and fewer girls are interested in STEM [41], [8]. When women arrive at college, departments struggle to recruit them to CS and other STEM majors. Even once a woman declares as a CS major, persistence rates are low and universities struggle to retain students.

II. Methodology

In light of these trends, we conducted a literature review to determine what professors, staff, and students can do to better retain female students in CS departments.

We primarily collected articles from the ACM Digital Library and the IEEE Explore Digital Library using combinations of the search terms "women", "female", "minority", "diversity", "education", "retention", "persist", and "university". No specific key words were required as inclusion criteria; but papers were required to discuss the retention of female students in CS programs at post-secondary institutions. For example, we excluded papers discussing students' retention of knowledge or differences in career goals between students of different genders.

Most of our sources are papers that were published in CS education conferences (*SIGCSE, ICER, FIE*). We also included some papers from Information Technology and Information Systems conferences (*SIGITE, SIGMIS*), conferences about humans and society (*SIGCAS, SIGCHI, SIGUCCS*) and psychology journals (*Frontiers in Psychology, Journals in Educational Psychology*, etc.). After collecting and reading an initial several dozen papers, we gathered papers which cited and were cited by the papers most relevant to retention of women in CS programs. Although we started with ACM and IEEE papers about women in CS, we found that many cited research about women in STEM. While it would certainly be preferable to only cite research about women in CS, we do reference several papers about women in STEM when we felt there was a lack of research on women in CS in a niche area.

Each paper was read in full; the main problems, proposed solutions, and key findings from studies conducted were recorded in a table. As shown in Table I, we broke research into four categories: first, static factors that were internal to female students, second, static factors external to female students, third, adjustable factors internal to female students, and fourth, adjustable factors external to female students.

	Static	**Adjustable**
Internal	Race, socieoeconomic background, GPA, ACT/SAT score, etc.	Self efficacy, study habits, academic goals, perception of field, etc.
External	Location of university, number of students, etc.	Content and order of courses, pedagogical styles, etc.

TABLE I
WE SORTED THE VARIABLES DISCUSSED IN THE LITERATURE INTO THESE FOUR CATEGORIES.

We chose to distinguish internal and external categories because changing the system is more sustainable than attempting to change the students [3]. We also separated static and adjustable into two categories. Research on retention that considers static factors often leads to future work like programs focused on students who are considered to be "at-risk" of leaving the major, while research on adjustable factors means the professors, staff, or students themselves can directly change their behavior.

These subcategories enabled us to recognize whether we could influence the variables in order to improve retention, and consider whether adjusting these variables would mean asking female students to change to fit in, or would be changing the culture of CS department and the world around the students.

Some variables, such as the "culture of a CS department", seemed to fit in more than one category: while the culture is external to students, students can impact the culture. Although the culture of a department can feel difficult to change, culture does change over time. We found that although the abstracts of many papers brought up broad subjects, the actual research, surveys, and studies tended to focus on more concrete subjects that were easier to categorize, like the impact of professors' lecturing style, school tolerance of pornography, and how involved students were in clubs. When an author was unsure about how to categorize a variable, we met and discussed it. We found that all variables discussed in papers about the retention of female students in CS could be sorted into one of these four categories.

III. Static Factors

We use the term "static factors" to refer to attributes that members of a CS department have only indirect influence over; attributes that they can attempt to change through programs, workshops, or courses focused on students who were found to be at greater risk because of these static factors. There are two inherent difficulties of these responsive or reactive programs. First, singling out a subset of students who are a minority race or gender could trigger stereotype threat [51]. Second, it can be difficult to tell if we are treating the symptom or the root of the problem: is the data causational or correlated? For example, are students who do not get enough sleep less likely to persist, or is there a deeper issue for which we do not have sufficient data? Perhaps a large portion of students who are not getting enough sleep are working over 20 hours a week.

A. Internal

This category includes things like a student's race, gender, socioeconomic background, GPA, or ACT/SAT score.

1) Academic background and prior experience: Although taking additional STEM courses in high school is helpful preparation [36], [62] for CS, later researchers noted that "women who are complete novices in computing are no less likely to persist than the most experienced women." [41].

Professors are unable to change college students' high school academics, but they can encourage students to take their current courses and extracurricular opportunities seriously. One survey found that encouragement from family, teachers, and peers, make up 28.1% of factors reported by high school girls as influencing their decision to study computing, larger than any other influencing factor [77].

2) Socioeconomic background: Female students of a particular culture [41], [14], [37], [17], country [22], [1], [20], or financial situation [41], [63] have persisted in CS programs at a higher rate than their male peers. Researchers have discussed possible reasons for many of these trends. For example, Gharibyan and Gunsaulus found that from nearly 20 years over 75% of CS students in Armenia were female; they note that the numbers may be bloated due to lower female participation rates in engineering fields [22]. Scniznel noted that in the 1990s undeveloped countries awarded about 50% of CS degrees to women, hypothesizing that gendered job markets, post-secondary educational system differences, and other cultural factors played a role [60]. While Galpin discusses the possible role of mandatory STEM courses, women-only schools, social class issues, and other cultural aspects on different countries diversity rates [20], further work is needed to better separate whether women of these backgrounds are more persistent in the aforementioned countries, or if female students in the US with these cultural backgrounds are also more likely to persist.

B. External

This includes things like the enrollment at a university, the location of the school, whether it is a commuter campus or a residential one, and other factors which are difficult for a CS department to change.

1) Geography, the university, & the department itself: The location of a university and the demographics of the overall student body are things that CS departments have either limited, or no control over. The ratio of female faculty is technically adjustable; however, it is influenced by who applies for openings, their qualifications, and other factors outside of departments' control. Cohoon noted that differences between CS departments' retention rates suggest factors like these likely play a large role [11].

While we found literature about retention rates of women in STEM across universities [68], and student personalities at universities with different cultures [57], more work could be done about CS departmental differences across universities.

2) Scholarships: Some female students report persisting through the CS major because switching out would cost them their scholarship [41]. However, other students report that not having a scholarship, but instead taking out loans to pay for tuition motivated them to persist in a difficult, but financially rewarding program like CS [41]. Speakers on panels at conferences like SIGCSE have recommended providing scholarships for tuition [74] and for students to attend research or diversity conferences like the Grace Hopper Conference, the Richard Tapia Conference, National Society of Black Engineer conventions, or Hispanic Society of Professional Engineers conventions [16], [5].

3) Support and encouragement: Encouragement from family and non-family plays a large role in persistence [26], [77]. While some studies found no significant differences in the self-reported about of encouragement received between male and female students enrolled in a CS course [4], others found that women receive less support from family and friends than men do [36], [77]. Female non-CS majors were more likely to feel that role models did not give them a good impression of CS [77]. A 1995 study of women who recently graduated with degrees in math or science found that if both parents were very supportive, the odds were 6.7 times greater that the woman would continue in science than if neither parent was supportive [55].

4) Stereotypes of Computer Scientists: Stereotypes about computer scientists include being socially awkward, wearing

glasses, and having pale skin [8]. These negative stereotypes deter many students from CS, but can impact female students more than male students. For example, a high school computer science classroom that did not project CS stereotypes caused female students to express more interest in taking CS than a classroom that contained stereotypically "nerdy" objects (like electronics, software, computer parts, tech magazines, Star Wars and Star Trek items, computer books, science fiction books, and video games), while there was no significant effect on male students' ratings [43]. A similar effect was found with course websites for introductory programming classes [46]. After a review of research on diversity in math and accounting, some researchers concluded that helping women understand that these are false generalizations could greatly transform technology [25].

IV. Adjustable Factors

We use the term "adjustable factors" to refer to attributes that members of a CS department—either professors, faculty, and staff, or the students themselves—can directly change.

A. Internal

In this section, we discuss adjustable, internal factors, like students' self efficacy, thinking habits, and academic goals. Some attributes are appear to be correlated with higher persistence, while others are causative.

1) Students' self efficacy: Even when controlling for ACT scores, females in the computer science major are significantly less confident of their computing ability than their male peers [4]. Some researchers have found that much of females' students' decisions to persist in the CS major is influenced by their confidence and self efficacy [14], [79], [59], [41], [19], [77], [34]. Unfortunately, it is likely that many of these female students are more harsh on themselves than they need to be [28], [32]. There will always be both men and women who decide to switch out of CS, but professors should be particularly cautious when students decide to leave because they are "not qualified"; a study of a cohort of students from the University of Pittsburgh suggests that CS departments are loosing students who are entirely capable and qualified, yet do not feel they are good enough [32].

Data from studies of CS students [59], [27], [41], [19], studies of students in non-CS fields [2], [28], [39], and studies of women in the workplace [33] show that women tend to have lower levels of confidence than men of comparable ability. Research from Carnegie Melon University suggests it is likely the case that students with particularly low confidence are more likely to drop out [41], [19], [42]. More research should be done to better understand the impact of student confidence on retention and possible interventions.

2) Thinking habits: Although many believe that female students are more likely to persist in CS if they programmed in high school, have relatives who code, love math, are anti-social, or fit in with other common stereotypes, the reality is, researchers have shown that many of these factors do not correlate with persistence [41]. According to some studies, the culture students were raised in, their personal philosophies, and their thinking habits are much bigger predictors of success [41]. By contrast, believing that failure occurs only because of insufficient effort, that hard work is just as important as natural talent, and that intelligence is malleable [41] were common characteristics of female students who persisted in the CS major. More recent research, such as a 2017 work-in-progress paper about non-cognitive traits like grit, found that perserveance of effort was a significant predictor for retention on the 1-2 year scale [9].

Sociologists, psychologists, linguists, and others from the humanities have enumerated many differences in how men and women think about and interact with the world. For example, Carol Frohlinger and Deborah Kolb popularized the phrase "Tiara syndrome," and explain that "Women expect that if they keep doing their job well, someone will notice them and place a tiara on their head. That never happens," [61]. They describe women as having the syndrome if they are less likely to speak up in meetings or ask for a raise. Deborah Tannen suggests that women are more likely to phrase suggestions as brief questions when men would speak at length in a declamatory voice.

Similarly, men and women often respond differently to the same comments: women are more likely to interpret a speaker's comments of sympathy or concern as the speaker's interest in connection, whereas men are more likely to view the same comments as the speaker's interest in showing power over them [69]. More work needs to be done to understand how these thinking differences between male and female students can impact the classroom, lead to feelings of isolation, or affect the retention rate when the gender balance is as extreme as it is in computer science.

3) Academic goals and career perceptions: According to a 2003 paper, female students are less likely to be career driven than their male peers are and are more likely to plan on taking a break from their career to have children [4]. This likely contributes to the fact that women are much more likely than their male peers to find unappealing some of the aspects of careers in CS, a field where 60 hour work weeks can be common [72]. Women are also more likely to view CS employment opportunities as anti-social [4], to underestimate the salaries of CS positions [4], to be less aware of different career possibilities [6], [77], and to connect what they are learning in the classroom with technical careers or practical applications [6], [72].

B. External

In this section, we discuss adjustable factors that are external to students, like the available clubs, the CS major application, faculty teaching styles, and the culture of the department.

1) Student involvement: Whether inside or outside of the classroom, research has shown that helping students feel involved in the department and other CS-related organizations is a key part of improving retention [41], [76], [18], [74]. Opportunities vary between CS departments and similar programs may have different names at different universities;

some departments may run mentoring programs, while others have student-run mentoring programs as part of Women in Computer Science (WiCS) clubs, or combined mentoring and networking programs sponsored by local companies. Research suggests that sending first and second year students to technical conferences can help increase their sense of belonging and self-confidence and may increase retention [80].

Research has found that increasing and strengthening student-professor relationships has improved retention rates at some universities [38], [41], as have WiCS clubs [76], [19], [41], [18]. Some universities have surveyed students about what aspects of mentoring programs or kinds of events students find to be beneficial [18], [76].

Women are more likely to believe that having friends in courses is instrumental in successfully completing the course [36], so friendship-oriented involvement can be particularly beneficial for women. Opportunities to help students get more involved can include building student-to-student relationships through mentoring programs [12], [74], [75], or providing opportunities for students to make friends in the major [16], [36].

Other ideas have included providing opportunities for students to work on collaborative coding projects [74], offering opportunities to tour local companies, interview for jobs, find career related service opportunities [74], [12], or get involved in research [38]. Research suggests that internships can have similar effects; a study at the University of Florida found that students reported internships strengthened their comment to stay in the CS major [31]. Researchers at the University of Nebraska found that career goals and more knowledge of career paths was positively correlated with persistence [52]. Other papers discussed the benefits of building students' job hunting skills by giving them opportunities to tour local companies, interview for jobs, and find career related service opportunities [74], [71], [12]. Other programs have included tutoring programs, which can help with the retention of both the tutor and tutee [74], hosting summer CS programs for high school students [74], or recruiting at local high schools and community colleges [12].

2) Applying to the major: Research suggests that the timing of when students apply to the major and which attributes a department chooses to look for in these applicants can make a huge difference in both recruitment and retention [5], [41], [36], [19]. Male students are much more likely to have prior coding experience than female students, but that was not found to be a predictor of success in computing at Carnegie Mellon University [41].

3) Content of courses and structure of the major: Many CS departments have attempted redesigning their introductory courses or changing how material is taught in order to make courses more engaging for female students in an attempt to increase the retention of female students [47], [23], [56], [19], [45]. Other universities are attempting to bridge tech and other fields in order to draw women into computing from other majors, like marketing and IT [25].

There are many research papers and books that discuss classroom environments and cultures and what professors can do to help female students feel more comfortable asking questions, participating, or working with TAs [21], [19] or the impact of flipped classrooms on retention rates [35]. When course content was changed, introductory classes began to use pair programming, and peer instruction increased, one university found an 18% increase in retention of students of all genders (from 71% to 89%) [53]. Female students who left the CS major at the University of Florida reported that one of the four main reasons for switching was a lack of timely feedback [30]. Focusing on the growth of a learning community can build the "women-CS fit", which facilitates women persisting in CS programs [19], [41].

4) Professors and teachers: Just as there are gender differences between male and female students, there are gender differences between how men and women mentor [65] and the impact of an instructor's gender or race on their students [54]. Other work has looked more narrowly at faculty's impact on recruitment and retention rates, finding that male faculty are as equally effective as female faculty at recruiting female students to STEM majors, but female faculty are more effective than male faculty in improving retention rates [15]. However, Griffith's 2010 paper about women in STEM fields found little evidence that female mentors make it easier for students to persist [24]. More work should be done about the role of faculty in CS departments.

5) Department policies: Currently only 15% of computer science faculty are female [10]; in 2016, Way et al predicted that gender parity will be reached around the year 2075 [78].

While there have been few studies about the impact of department policies on recruitment and retention, there have been panels [16], [73] and SIGCSE bulletins [12], [72] which make recommendations about departmental policies. For example, there is discussion about the importance of hiring female role models (both TAs and professors) [12], [74], maintaining a stable faculty, hiring non-research faculty who focus on teaching [12], training new TAs [74], providing sufficient institutional support and resources (TA hours, open lab computers, etc) [12], and requiring students to meet with an academic advisor before quitting the CS major [74].

Other recommendations include standardizing the methods by which students receive information—women are more likely to be excluded from social networks, for example—and making accommodations for graduate students who wish to make time for social or family life [38]. Trainings and workshops to educate professors about the impact of gender stereotypes that impact women in STEM have had mixed results [29].

6) Department culture: McLoughlin breaks gender bias into three distinct predispositions: overt, covert, and subtle [44]. Cottrell's 1992 paper, "I'm a Stranger Here Myself", described women's graduate school applications being tossed out because of the applicants' gender, pornographic screen savers on lab computers, and female students being instructed to wear two piece swimsuits to parties [14]. While this kind of overt sexism has not been reported recently, recent literature

gives many examples of covert and subtle sexism in CS departments [13], [41], [78], [75]. While sexism is toxic to women, it is far from rampant [13].

Professors may use stereotypical examples of men and women's roles, make sexist jokes, be more likely to make eye contact with male students than female ones, call on more men than women, or give more help to male graduate students with designing research, writing grant proposals, or coauthoring publications [13]. Peers may comment on female students' admittance to programs in a demeaning way, suggest that women were "only good enough" to earn women's grants or awards, exclude female students from social groups, or fail to take female students seriously [13].

Cohoon et al's 2009 paper suggests that departments need to teach students how to report sexism and inform students what happens when the Title IX office is contacted [13]. Students can be hesitant to report covert or subtle sexism [72]. When female students consider leaving a graduate program due to sexism in the department, they were found to be 21 times more likely to leave than students who consider leaving for any other reason [13]. A 2018 study at the University of Florida found that female students were twice as likely to consider leaving CS than their male peers, and female students reported that two of their four main concerns were presence of gender biases in the classroom and negative team experiences [30].

V. Conclusion and future Work

From this literature review, we hoped to gain insight into the question: what can students, faculty, professors, departments, and universities do to improve retention rates of female students in computing? It is clear that there is no single answer; rather, departments will need to find what works best for their situations.

Research spanning over 40 years shows that women are capable of and interested in computing. Diversity efforts can be broadly separated into two different categories.

Static factors, either internal or external to a student, like academic or socioeconomic background, the geographic location of a university, scholarships and internships available to to students, the support a student receives, or the impact of stereotypes and social pressures cannot be changed directly. Interventions can be planned for students who are more at-risk than others, but interventions should be designed to minimize the risk of stereotype threat to minority groups. but interventions should be designed to minimize the risk of stereotype threat to minority groups.

Adjustable factors can play a huge role in a student's success in computing and their persistence in the CS major. Factors internal to a student, like their self efficacy, thinking habits, academic goals, and perception of careers can make them more or less likely to persist. External factors, like the process of applying to the CS major, the content and structure of courses and the CS major, the professors, and culture of the department are also key variables. Some factors, like student involvement, are both internal—students choose how involved they will be—but also external—student involvement depends on what mentoring programs or clubs the department offers.

Internal factors cannot be controlled directly by the department, but workshops and other interventions can impact these factors. Future work should consider the risk of imposter syndrome for minority students as well as other implications of such research. If we say we are adjusting these factors to improve diversity, then should we really be trying to change the women? Are we trying to make female students just like their male peers? Some changes, like increasing female students' self efficacy, seem to be inherently good and have no drawbacks. However, other changes, like encouraging women to use particular communication styles, are not obviously good. If successful male students tend to be more direct and assertive, should we try to make our female students be more direct and assertive?

Sheryl Sanderburg's "Lean In" discussed how women can choose to adopt stereotypically male traits in order to be more successful in educational or workplace hierarchy [58]. However, more recently, there has been discussion of encouraging women to work to change the educational or workplace hierarchy instead of changing themselves to better fit in [7], [64].

Future work could also include things such as:

- The impact of particular courses or assignments on students' confidence or self efficacy.
- What interventions can help students build confidence or self efficacy.
- Similar questions can be asked about students' thinking habits, their academic goals, and involvement in the department.
- Collecting data across multiple universities for generalizable results.

Additionally, researchers have already noted that there is a lack of research on retention of minority-race [54], [70], [40], [54], [66] and LGBTQ+ students [67], [54]. As Margolis et. al noted, these students face unique difficulties and often have fewer opportunities to get involved in tech, particularly in K-12 settings [40]. Research regarding improving the retention of these minority groups in CS will likely prove to be relevant to retaining female students.

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