Board 208: Breaking Through the Obstacles: Strategies and Support Helping Students Succeed in Computer Science

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Breaking Through the Obstacles: Strategies and Support Helping Students Succeed in Computer Science

Introduction and Motivation

Not only that there is a continuously growing number of students who want to study computer science (CS) but also there is a large need for CS graduates. The computing jobs are crucial for the development and growth of the economy worldwide. For example, the data from the Integrated Postsecondary Education Data System (IPEDS) [1] by the U.S. Department of Education's National Center for Education Statistics (NCES) [2] and the US Bureau of Labor Statistics (BLS) [3] for the academic year 2020-21 shows that the number of available jobs nationwide, greatly exceeds the number of nationwide graduates. There is a total of over 4,700,000 Computer Science job openings that cannot be satisfied by the current graduating cohort. The prediction for the next 10 years shows substantial potential for job openings with an average predicted job growth rate of 18%. Moreover, BLS shows that the median pay per year ranges up to $150,000, showing strong positive job prospects. Overall, the unfulfilled need and high median pay strongly demonstrate the impact of obtaining a computing degree, for individuals and the nationwide economy.

Colleges and universities have been seeing record-high numbers of CS majors, and many programs need to limit admission to the CS major or courses [4]. University and CS department policies have an important role in the decision of who has access to CS and, consequently, who can obtain the degree. Even though Camp at al. [4] report growth in the representation of women and students from underrepresented racial and ethnic groups, the demographic of CS students is highly skewed toward males versus females and has skewed racial/ethnic distributions [4, 5]. CS has particularly imbalanced gender and racial/ethnic distribution within student populations [6], resulting in imbalanced representation in the workforce. For example, Fry et al. [7] found that Hispanic and African American workers are quite underrepresented in the U.S. CS workforce. They make up 17% and 11 %, respectively, across all occupations, but only 8% and 7% of CS workforce, respectively. Additionally, women are 51% of the population, but only 19% of the CS workforce, as of 2018. Similar gender and race/ethnicity breakdowns are shown in our institutional data (Section *Institutional Data and Demographics*).

While existing literature confirms gender and race imbalance in CS [8], there is a limited investigation of institutional, pedagogical, and cultural influences that lead to a lack of student

retention [9]. Our NSF project leverages both qualitative and quantitative studies to provide insights into the structures that either support or undermine a minoritized student's ability to excel in computer science. The comprehensive goal of this NSF project is to explore when and to which degrees these imbalances are greatest and how the imbalances may influence students' opportunities to enter and paths throughout CS undergraduate programs. This poster/paper will present a portion of our findings obtained during **a pilot qualitative study** related to strategies and support for overcoming obstacles through a variety of actions (policies, programs, pedagogy, culture) toward student success. This paper/poster will focus on the following research question: *What are the strategies, structures, and scholarly attributes that support student experiences as per student's lived experience?*

We designed the pilot study to validate our study instrument, namely, to test our protocol and questions. The pilot was run in three different institutions of higher education in California and is designed to dive into the students' lived experiences describing their pathways to and through the CS degree. We ran the pilot until we reached saturation when we did not obtain any new data from the introduction of the new participants, resulting in a total of seven participants. The pilot study used a population of convenience: a limited population of students who are soon to be graduated or graduated. Three of the participants self-identified as women and four as men. We also explored whether focus groups or individual interviews provided the most effective means for elucidating meaningful data. We organized one focus group (all women) and four individual interviews (men). The focus group provided a comfortable environment and might have facilitated synergistic outcomes through participant interaction.

Our findings illustrate lived experiences and brought several issues to light. Positive experiences included engaging pedagogy, prior CS experiences, a summer bridge program, a research experience, and a feeling of belonging. Negative experiences included dry pedagogy, competitive situations, cliques being formed, and challenging team dynamics. The collaborative work environment showed positive and negative aspects, pointing to the need for a well-defined collaboration policy. Collaboration and team dynamics influenced social engagement and a sense of belonging that has been known to significantly increase success, retention, and graduation rates. We noticed the differences in the level of preparedness and its influence on the student's perception of their journey. We also explored the influence of soft skills, outlook, scholarly attributes, and support on the perception of the journey through the program. Although our participants have reported that they did not perceive any overt sexism or racism, we present the findings correlated with gender and race/ethnicity.

Our future work will include fine-tuning the protocol to explore intersectionality and reflect upon the situations where the students might feel minoritized. Additionally, the students in the future study will be purposefully selected to examine experiences at multiple stages of the major with different support and preparation for a CS major (SES and first-generation status), or the students who are at risk of dropping out or who have already dropped out as they may reveal reasons and circumstances for attrition.

Literature Review

Our team investigated the lived experiences of students on their trajectory to and through Computer Science. According to Tinto's "Model of Institutional Departure" [10], the best way to have student persistence and retention in Computer Science is to integrate positive formal and informal academic systems (such as academic performance and staff interactions) as well as formal and informal social systems (such as extracurricular activities and peer-group interaction). We present the review of related work as per themes that our analysis has discovered.

Previous Experience: Barker et al. [11] have found that prior experience is a powerful indicator of students' intention to persist in CS. Moreover, previous high school STEM experience [12], in particular having taken AP CS classes [13], indicate retention and better college CS grades. Similarly, Alkhasawneh et al. [12] positively correlate previous programming experience with retention and grades. However, large gender and racial disparities exist in students who take and pass AP CS Exams [14]. Our student participants did not report on their AP classes taken, hence this is an area of further inquiry.

Other studies have shown that pre-college CS experience is associated with high motivation and higher grades in both introductory and some upper-division CS courses [15, 16, 13]. Weidler-Lewis et al. found that the best predictor for women's persistence in CS is access to early computing and programs in middle schools and high schools [17, 18]. Margolis [19] noted that for students from underrepresented groups, the problem was compounded in the schools. Schools that had rich curricular resources in computing were usually situated in predominantly White areas, while those in predominantly Latinx or Black areas had hardware resources, but limited curriculum and teacher expertise. Our participants appreciated prior experience, and a few who lacked it still performed well. However, we had a small population of successful students and did not draw conclusions based on gender and race/ethnicity. We acknowledge that our findings may change as we perform follow-up with a larger number of more diverse students (Sect. *Limitations*).

Programs and Clubs: Barker et al. [11] have also found that student-to-student interaction is a powerful indicator of students' persistence in CS. Moreover, Fox et al. [20] reported that peer mentoring programs are efficient ways to enhance students' retention and success, and Budge [21] showed that it is beneficial to communities to engage in cooperative learning. Especially for minoritized students, the mentoring program can significantly improve their participation and success in CS [22].

The interviewed students also reported the strong positive impact of supportive peers (Sect*Programs and Clubs*), and one of them also pointed out the need for widespread targeted outreach. This aligns with the findings of Barker et al. [11] who noted that if the institutions do not have strategic recruitment for minoritized students, programs cannot close the equity gap simply because they are not reaching minoritized students.

Pedagogy and Mentoring: Challenges arose from the surge in CS enrollment within the last decade. Many programs have faced significant problems, such as classroom space, inadequate

numbers of faculty/instructors, TAs, faculty workload, and lack of office, and lab space [4] which affected the student population in terms of admission, retention, and success. However, inequities can be minimized when computer science educators center their instruction around equity and inclusivity [23]. Studies examining the influence of classes, instructors, pedagogy, and CS programs have found that relevant and meaningful assignments, faculty interaction, and collaboration with peers on programming assignments were all associated with higher retention rates across all groups of students [11, 24]. Moreover, in addition to the course content, the instructors must implement techniques to frame the classroom for students who have less experience in CS and be aware of their own identity and biases to facilitate retention [18]. Also, it has been shown that research opportunities are one of the essential factors in retaining students [25, 26], especially for minority-serving institutions.

According to Biggers et al. [27] the main reasons for attrition in CS are students' perception of lack of exposure to the big picture of CS, coursework lacking in relevancy, the community being asocial, the workload as tedious, boring, time-consuming, and a lack of understanding of CS career opportunities. Salguero et al. [28] outlined pedagogical strategies that might address the above obstacles, such as the inclusion of media computation[29], pair programming, and peer instruction, which helped create a supportive environment and resulted in lower failure rate, higher retention in the major, and narrower achievement gap for all students. Additionally, flipped classes and active learning were shown to improve the class GPA and the total number of students who earned a passing grade [30].

The interviewed students emphasized the impact of supportive pedagogy (Sect *Pedagogy and Mentoring*): from contextualized approach to supportive and inclusive attitudes. We also discovered that the students benefit when the instructors motivate each unit or encourage engagement in research, which in turn results in both increased confidence and belonging.

Belonging: Having a sense of belonging among students is directly correlated to recruitment and retention [31]. Students who feel they fit in tend to persist and graduate with a CS degree. Our findings align with the findings of Baker et al. [11] that student-to-student interaction contributes to success. We found that peer, instructional, and staff support strongly contribute to the feeling of belonging. We also found that the efforts to create a community, using programs, are beneficial to belonging and success.

As per the Integrated Interest Development for CS Education (IID/CS) framework [32], matching college students' interests contributes to increasing diverse students' sense of belonging in CS, which also can improve retention. Moreover, Garcia et al. [33] showed that incorporating elements of inclusive design in "regular" CS (non Human-Computer Interaction) courses across an undergraduate curriculum resulted in significant improvements in students' course outcomes, especially for marginalized groups, and that also significantly improved inclusion and teamwork in the courses. Similar to the above, our findings show that pedagogy may significantly influence the sense of belonging.

Garcia et al. [34] found that even high-achieving minoritized CS women were less likely to have

CS identity, to see themselves as CS people, or to feel recognized in CS, compared to men. So far, we have two men reporting that they sometimes felt that they did not fit in, citing the highly competitive nature of the major.

Collaboration: Not only that peer collaboration [11, 35, 24] contribute to higher retention rates, but also we found that collaboration further solidifies the sense of belonging, hence the student success. Umapathy et al. [36] reported that student learning outcomes and performance are usually higher in collaborative learning scenarios (i.e. using pair programming) than in individual learning scenarios (i.e. using "solo" programming).

However, creating an environment for successful collaboration and learning teamwork is not an easy task. Shults et al. [37] performed a qualitative study with the students and instructors and found that collaborative and cooperative learning are not frequently applied in higher education CS classes. They found that the instructions on how to collaborate are insufficient (e.g. only group size is defined) either because of instructors' lack of knowledge about how to foster collaboration, the assumption that the students already know what to do, or the view that collaboration is a means to an end (project completion) rather than the acquisition of (teamwork) skill. There is also a concern if all students will learn the required skills and reservations about the student assessment. Additionally, the students acknowledged their responsibility: they need to make sure that they are involved both in the learning of course topics and in teamwork. Our findings align with this study: the students have various experiences and there is a need to define the scope and rules for collaboration. We also found that collaboration usually happens later in the program, and it may contribute to a sense of belonging.

Outlook: The students' outlook is an important factor from the selection of a major till graduation. Several large-scale quantitative modeling studies have concluded that students' comfort level/self-assessment of their understanding, identity, and sense of belonging, in addition to their math background are factors associated with success in CS courses [38, 39, 40, 41]. Whereas, Lewis et al. [42] emphasized that perception of the student's abilities was a major factor in their decision to study computing.

Lastly, the students might be left behind if they do not know where to ask for help. Even though it is the student's responsibility, the environment like family, friends, advisors, and teachers plays a significant role [12]. Our findings also highlight the need for self-advocacy but also add the importance of having a growth mindset.

Policies and Staff Support: Redmond et al. [15] discovered that early exposure to CS is one of the most critical factors for women to choose a CS career. Orthogonally, Wang [43] correlated financial aid with STEM major selection. While our student participants witnessed the impact of exposure, staff support, and supportive policies, we did not explicitly investigate financial factors. We propose to investigate the influence of financial aid and other SES factors using quantitative analysis and to recount the population of varied SES.

Gender and Race/Ethnicity: Students from minoritized groups in CS, as defined in [44], are underrepresented due to both entry and high attrition (switching majors or dropping altogether). For example, women are less represented in the CS field due to pre-entry, institutional, and societal factors [45]. Oftentimes, minoritized CS students may experience a culture of racism and sexism [46]. Warner et al. [47] used the Disparity Tool to determine equity in CS education across multiple underrepresented groups. For example, rural, black female students were affected more compared to other underrepresented groups [47]. The gender breakdown of the three observed institutions is aligned with the nationwide trend of heavy male enrollment in CS programs. In some universities, the gender gap widens after the introductory CS course, as fewer women continue in the major [48].

Corell [49] found that women believed "they had to earn a score of at least 89 percent to be successful, but men felt that a minimum score of 79 percent was sufficient to be successful". Additionally, female students are more likely than their male counterparts to leave CS programs after receiving a "B" grade [50]. Therefore, the perception of success (grade, and test score percentage) differs significantly across genders and might be a significant indicator of retention and graduation. Additionally, Panic and Clarke-Midura [45] found that despite the unequal representation of genders in computer science, gender is not a significant predictor of a student's ability to perform well in computer science. Interviews with females revealed a mix of opinions on whether gender was a problem in CS [51]. Some agreed gender was a problem, some were neutral, and some were frustrated with the focus on gender [51]. We want to explore the impact of Gender and Race/Ethnicity using updated interview questions but also look at intersectionality and combine the qualitative analysis with the findings of our ongoing quantitative studies.

Methods

The qualitative pilot study was designed to contribute to overarching project goals, by providing student voices and discovering the reasons behind disparities in representation. We piloted an interview protocol with undergraduate students for qualitative data collection and analysis to complement the ongoing quantitative study. This paper/poster focuses on the portion of the **qualitative analysis** that answers the research questions in Section *Introduction and Motivation*. The interview protocol was IRB-approved in all participating institutions (IRB protocol numbers: 1354049, 2019 SP 59-R, and 201331).

Population

Institutional Data and Demographics

We piloted the protocol at three four-year universities, for which we presented an overview of student demographics (Figure 1). The aggregated statistics refer to Fall 2022.

Institution 1 is a public university with a significant emphasis on undergraduate education, with 32,711 students attending. 58.2% of the students are female, 52% are of an underrepresented minority, and 30.6% are first-generation students. The CS department has 1,770 students, with

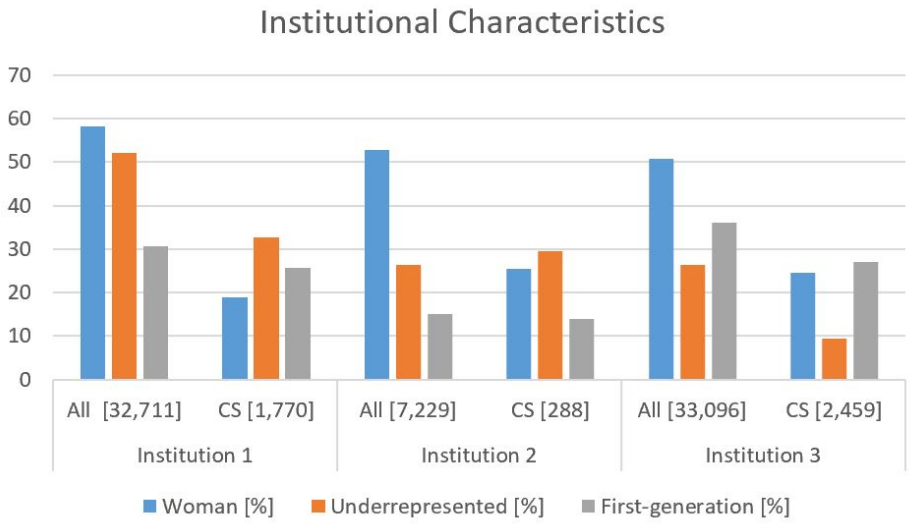

Figure 1: Institutional Data and Demographics

18.8% female, 32.7% of an underrepresented minority, and 25.7% first-generation students. Institution 1 has also been recognized by the United States Department of Education as a Hispanic and Asian American and Native American Pacific Islander-Serving Institute.

Institution 2 is a private university that offers a rigorous, comprehensive education to its undergraduate students. 7,299 undergraduate students attend Institution 2, with 52.9% female, 26.4% of an underrepresented minority, and 15.1% first-generation students. Its CS program is made up of 228 students, where 25.4% are female, 29.4% are of an underrepresented minority, and 14% are first-generation students. Institution 2 has been designated as a Hispanic Serving Institution by the Hispanic Association of Colleges and Universities.

Institution 3 is a large public university with strong programs in the STEM fields. 33,096 students attended Institution 3, with 50.8% female, 26.4% of an underrepresented minority, and 36% first-generation students. 2,459 are in the CS program, where 24.6% are female, 9.4% are of an underrepresented minority, and 27% are first-generation students. It has been recognized as an Asian American and Native American Pacific Islander-Serving Institute by the United States Department of Education.

Participants

A total of seven students from three different institutions participated in the pilot. The students signed informed consent. Three of them self-identified as women, and four as men. Additionally, two identified themselves as White/Caucasian, one as White/European, two as Asian or Asian American, one as Hispanic or Latino, and one more participant chose not to report their Race/Ethnicity. None of our participants were first-generation or transfer students. Furthermore, five reported that they are seniors (either entering their senior year or just graduated), one reported that they are both senior and post-bachelor and one more reported that they are junior.

Table 1: Institution Demographic of Participants

Institution	Gender Identity	Race/Ethnicity	Academic Level
Institution 1	2 Men	1 White/European & 1 Asian/Asian American	2 Seniors
Institution 2	1 Woman, 1 Man	1 Hispanic/Latina & 1 White/European	2 Seniors
Institution 3	2 Women, 1 Man	1 Prefer not to say, 1 White/European & 1 Asian/Asian American	1 Senior, 1Junior & 1 Senior/Post-Bac

Additionally, one student shared that they are a double major and another student shared that they are a data science major, which is related but not equivalent to a traditional CS program.

We conducted one three-person focus group (all participants identified as women) and four individual interviews (all participants identified as men). We employed a mix of focus groups and individual interviews to observe the two modalities for the efficiency and comfort level of the participants. We also were cognisant of the participant's time and if the focus group modality resulted in the interaction between the participants that brought in the added value compared to the individual interviews. In Section *Limitations* we state the limitations of the populations participating in the pilot study, the grouping of the students, and discuss the ways to address the issue.

Table 2: Participant Demographic

Pseudonym	Gender Identity	Race/Ethnicity	Academic Level
Emma	Woman	White/European	Senior
Samantha	Woman	Hispanic/Latina	Senior
GraceS	Woman	Prefer not to say	Junior
Jacob	Man	White/Caucasian	Senior
Riley	Man	Asian/Asian American	Senior
Lance	Man	White/Caucasian	Senior
Yoshi	Man	Asian/Asian American	Senior& Post-Bac

Data Sources

The interview questions were designed to support the overarching project goal of researching computer science recruitment, retention, and graduation through the lived experiences and perceptions of undergraduate students. The team was especially interested in the voices of those typically minoritized in computer science, as per NSF definition [44]. The interview questions were developed to align with the literature and research goals. The questions were curated by the research team of computer science and science education researchers and graduate students. The

team tested them on one individual, and based on their feedback, fine-tuned and pruned the questions further to shorten the time necessary for the assessment while being careful to retain the exploration of major themes and issues. For the sake of completeness, we present below all interview questions used in our broader study, with the follow-up question given in parentheses. However, after analyzing the interviews, we selected the answers pertinent to the research question presented in this paper/poster, as the full analysis of all topics requires a much larger space.

1. Please tell us what it has been like to be a computer science major at your university.
2. Choose three words that would describe what it's like to be in your computer science classes.
3. Do you feel like you fit well into your program? Why or why not?
4. Thinking about your time at your university and your time before you went to college, what do you think are some of the most important experiences or supports that you have had that have helped you succeed in computer science areas?
5. What kind of obstacles have you faced in computer science or in your computer science classes?
6. Think about one of your most recent computer science classes. In that class, how did it affect your desire to want to continue to move forward in computer science? Are there parts of that class that helped you to say, "Yes, this is the right thing for me." Or are there any issues?
7. Was there ever a time when you thought about leaving the computer science program, and if so, what might have made you think that way? (How likely are you to stay? Was there anything at any time that really made you think that "I'm not sure that this is what I want to do", and why?)
8. Do you mainly work by yourself in your classes and classwork, or do you mainly work in teams or pairs? What in your opinion would be the advantages and disadvantages of working with a partner or a team?
9. Have you ever felt that there was sexism or racism taking place in your program or your class? What made you think that or feel that way?
10. Are there any policies or procedures in your university or a class that you think helped or hindered you? (It could be anything like enrollment or applying to the program, or it could be assignments. Are there any hindrances or things that helped you in terms of structures or procedures?)
11. If you could change any parts of your program, what would you change?
12. Is there anything I didn't ask you that you would like to share about that you think would be helpful?

Table 3: Findings: Themes Discovered

Major Themes	Sub-topics
Prior Experience	high school (STEM/engineering) programs and internships
	high school computer science and math modeling courses
	community college programming courses
Programs and Clubs	bridge programs
	summer programs
	clubs
Pedagogy and Mentoring	(interdisciplinary) collaboration
	teaching style: active/hands-on learning, applications
	presenting motivation and the big picture
	empathy, responsiveness, flexibility, and commitment
	encouraging/supporting research experience
Belonging	bridge and research programs
	shared lab space
	peer support (in-class support, and "women-to-women" support)
	highly competitive nature of CS (cliques)
	majors looking down upon CS minors
	pedagogy that promotes competitiveness
Collaboration	working in small groups (upper-division courses)
	work independently (lower-division courses)
	choose the group members
	encourages thinking the problem through before implementing
	helps learn from different perspectives
	interpersonal dynamics and secrecy
	enjoy autonomy and challenge
Outlook	independence and self-accountability
	not afraid of failure
Policies and Staff Support	long prerequisite chains
	professors prioritized research (RTP policy)
	classes that are too big to connect
Gender and Race/Ethnicity	never felt sexism or racism
	recognizing the challenges
	different treatment due to gender or race/ethnicity
	gender ratio within the program is improving

Interview Protocol and Procedures

The same senior researcher performed all interviews in this study. We conducted one three-person focus group (all identified as women) and four individual interviews (all identified as men). We employed a mix of focus groups and individual interviews to observe the two modalities for the efficiency, time, and comfort level of the participants. We wanted to observe if the focus group resulted in synergy between the participants which created added value compared to the individual interviews. The interviews were conducted via Zoom and recorded. The transcription was done using a third-party service [52] and the researchers de-identified the participants, and assigned them pseudonyms, which we use in this paper/poster.

To process the interview data, the research team employed constant comparative qualitative analysis [53] with emergent coding. The analysis was performed by the first, second (senior researchers), sixth, and seventh (junior researchers) authors. The researchers read the interviews and examined all the interview data. They identified units of data (phrases, sentences, or paragraphs that can stand on their own as meaningful data) and assigned them initial codes. The junior researchers together coded each piece of data using emergent coding under the supervision of the senior researchers, resulting in a larger set of codes. After examining data from three individuals, the codes were further organized hierarchically into larger thematic groups and subgroups. The subgroups were kept to maintain the richness of the variety of codes within a group. Codes were further adjusted and the groups were refined after each additional interview analysis. The coding and hierarchical organization of codes were done through a discussion until a consensus was reached. A final refinement of the codes and interview protocol was done by the senior researchers after all data had been processed.

Findings

We present the findings from the qualitative data analysis grouped per broad categories. Some findings organically correspond to more than one category. We decide on the primary category, but mention it in others as well. Additionally, we focus on beneficial practices but mention some obstacles. We focus on presenting the student's authentic voices using the quotes. We cleaned up the filler words (”like”, ”um”, ”ah”) and added context in square brackets when needed. The summary of findings is shown in Table 3.

Prior Experience

Most of the students (mixed gender and race/ethnicity), who had prior experience in CS felt more prepared for university-level courses. Prior experience included participation in **high school (STEM/engineering) programs and internships**, **high school computer science** and math modeling courses, and **community college programming** (C++) courses. A woman (who did not disclose race/ethnicity) shared her experience focusing on two helpful programs.
Grace: “So I went to more of a STEM focus school, so we had a PLTW [”Project Lead The Way [11]] . . . I was in the engineering pathway. So it's basically where you have an engineering class every year that you're in high school. And the third year is computer science. So I took a computer science class then, and since I was also technically taking an engineering class the other years, where it was basically, you learn about the design process, you try to make different

prototypes for things. I was familiar with the general engineering process and what it would be like sort of."
Grace: "And there was also a program in San Diego called Marine Technology Society. . . . And they would place high school students and internships. So I was able to do a small internship over the summer for six weeks. And I didn't know anything, so I wasn't very useful, but just having the experience of being in the office and seeing what everyone else is doing was pretty interesting. And that definitely gave me a good amount of experience, I think too, going into university.

Another woman (White/Caucasian) testified to the importance of **early start with CS/coding**. Her experience translated to **growth mindset** regarding code development and the difference from other subjects, thus positioning her for success.
Emma: "Yeah. I mean, I had a coding background, and I wasn't big on computer science, but I did take a math modeling course my senior year of high school so that definitely helped...[It helped with] Debugging skills... I was used to staring at code and not being surprised when it didn't work. I know that there are other students who are very frustrated with that who had never had that experience before, because when you solve a math equation or something, you don't know if it works or doesn't work until you plug it back in and see, but obviously with code unexpected things arise.

A man (White/Caucasian) reported that **a positive, previous (high school) experience** helped him feel that he fit in right from the first programming course (CS1).
Jacob: "Well I've always wanted to do computer science even when I was in elementary school or something. I just, I love technology. So in high school I took computer science classes. I knew right away in college, I wanted to take computer science classes. Um, so I felt like I belonged, even in the first Python class I took freshman year."

Because of no prior experience in computer science, one White/Caucasian man fell "behind" in content understanding. However, another student (man, Asian/Asian American) mentioned that prior experience did not always translate into university-level coursework, suggesting that there is a disconnect between pre-college CS education (whether formal or informal) and post-secondary CS programs. Additionally, both a woman (Hispanic/Latina) and a man (Asian/ Asian American) reported either no exposure or no understanding of "what to use CS for".
Samantha: "In high school, I didn't know anything about computer science. I did barely even know what it was or what it entailed, how to use it, how it could help me with mathematics."
Riley: "I went in without knowing anything about Computer Science."
Overall, the students did not perceive explicit differences that relate to gender or race/ethnicity but only related to academic preparation and exposure. However, some of the programs that had pivotal roles in student's career were targeting traditionally underrepresented populations.

Programs and Clubs

Two students specifically mentioned the value of **bridge programs, summer programs, and clubs**, which allow underrepresented CS students to develop not only **skills** but also a **supportive community** with the university. Some of the programs provided exposure during high school (like "Project Lead The Way and a program with Marine Technology Society, see Section *Prior*

Experience) and some just before entering the university. A woman (Hispanic/Latina) spoke of the power of their **summer bridge** experience and noticed the **need for more outreach targeted to underrepresented populations** on an ongoing basis. In this case, the positive experience from the bridge program motivated the student to enroll in a double major, despite originally not having any interest in CS.
Samantha: [talking about bridge program targeted to underrepresented populations] "...it was open to students of all levels from experience to no experience, you just needed to have an interest in it. And so I decided to just try it out and it was really helpful, and I'm really glad I did... Because initially, computer science was not... I wasn't going to touch it. . . . And then I did this program and I liked it, and so I took a class and then eventually I kept taking classes and it became my minor, and then I was halfway through, so I figured I might as well add another major if I have the time and inclination."
Samantha: "Honestly, I don't really have any complaints except for that summer bridge program for it to be bigger because it only had 18 students, I think if more students could do it, the better, but that's all on donor funding... I think there should have done more marketing for the program."

Another woman (who did not disclose race/ethnicity) testified about the contributions of the **programs and clubs** during her time at the university, which helped with community building.
Grace: "There's been a lot of programs to help support me, like ERSP (Early Research Scholarship Program), and there's also a lot of clubs like Women in Computing, and Society of Women Engineers. And I think having that community of people that I can talk to or just send a message to whenever I need help with something, whether academic or just even to talk with or hang out with, I think that was really helpful."

Interestingly, the comments in this category were provided solely by women (Hispanic/Latina, and the one who did not declare race/ ethnicity).

Pedagogy and Mentoring

Many students perceived computer science as challenging, yet fun and exciting, and often related the notion to pedagogy or experiences with their mentors. Pedagogy that encourages **(interdisciplinary) collaboration** helps the students learn from different perspectives (see Sect. *Collaboration*). All students emphasized the positive influence of a **teaching style** that included **active/hands-on** learning. Students particularly enjoyed seeing computer science **applications**, both in their coursework and hobbies. A student (White/Caucasian man) shared his excitement about projects that tie to pop culture and games.
Jacob: " [talking about projects]...it doesn't even have to be a GUI or a geographical user interface, um, it can just be like, for example, Prof Y... she did a Wordle [54] project with her [CS1] students, which I think is cool, exciting, compared to the project I did, which was (laughs)...but at the end of the project, you know, you have something that you can play and you can show off"

Another student (men, Asian/ Asian American) appreciates when the instructors provide **motivation and the big picture** for the upcoming unit.
Yoshi: "So, I think just motivating stuff with a problem that you're going to solve using them

might be helpful... 'This is what you'll be able to do with...' I think, even just to sprinkle that in a few times, that would be helpful."

Additionally, pedagogy and instructors' outlook help the students feel supported when the professors show **empathy, responsiveness, flexibility, and commitment**. Two women (White/Caucasian, and one who did not report race/ethnicity) shared that those practices resulted in them feeling supported and welcome.
Emma: "So I imagine this extends to other departments as well at INST X. I felt like if someone had a problem or an issue, whether that's something deadline-related or content-related if enough people said something, an action would be done, and actually that also happened throughout the university as well with COVID and being able to take no pass classes and stuff. So I felt like that was a recurring theme in my undergraduate experience. But personally, I feel like I got a lot more support from the instructional staff than my peers."
Grace: "Yeah. I've also had a really positive experience so far. The professors have been really welcoming, and especially in the lower division classes they made sure to go over every little thing and not make assumptions about how much you know previously... And I think a lot of the lower division professors have some research related to CS education. So they definitely care a lot about teaching you well, it's something that's important to them, and I think it definitely shows."

Moreover, the students appreciated the use of **pseudo code** for problem-solving (other than a specific programming language) both in class and for assessments. One student (White/Caucasian man) particularly credits a professor who strongly encouraged him to become a **research assistant**, despite not having prior experience. Some students remarked on the need for required time/effort to accommodate out-of-class workload, stating that the **content**, rather than pedagogy, is the reason for *time-consuming homework assignments*.

The students reported that dry, lecture-based pedagogy resulted in feelings of being stressed or frustrated, which may lead to a lack of interest in CS. Moreover, the use of AI for plagiarism checks, due to the perceived large number of false positives, is a sore spot.

Overall, we noticed students' appreciation for contextualized pedagogy and the need for meaningful application of learning to personal and professional self, as well as supportive pedagogical and mentoring practices.

Belonging

Most of the interviewed students stated that they either **fit in** or at least that they "did not feel like they do not fit in". Attending **bridge and research programs** (as in Sect. *Prior Experience*) helped to create an initial cohort that aided a sense of belonging. Moreover, being **a part of a research lab**, and hence **sharing a lab space** also resulted in peer support, and hence in belonging. Additionally, **pedagogy** may contribute significantly when the students feel supported (Sect. *Pedagogy and Mentoring*). **Peer support** was positively recognized by all students, highlighting, **in-class support**, and **"women-to-women" support** (as in Sect. *Programs and Clubs*). A woman (Hispanic/Latina) emphasized the impact of the **supportive peers** that was aided by an inclusive Slack channel.

Samantha: "And then also having access to this giant Slack channel with all the computer science majors, it made it easier if I needed to ask for help, even people that I had it... it did take a lot more guts to just reach out to a random classmate, but at least I knew that if I wanted to reach out to them, I could just find their name in the Slack channel and like, "Hey, we're in the same, this class, can you help me with this or that?" And I joined the Slack channel since my first computer science class because anyone can join it, you don't have to be a major, and that's what helped I think."

A man (White/Caucasian) shared that working in **small groups** helped his feeling of belonging. He mentioned it was easier to connect with the **peers who persevered**.
Jacob: "Group projects are really cool and they're great for collaborating and making friends... [But] group projects didn't take place until the junior year... Throughout college, I felt like... more people that made it through, felt like they belonged and it was easier to find friends, easier to have people that wanted to be there... [it took], two, three years."

Even the students who stated that they fit in shared the aspects of their experiences that negatively influenced their sense of belonging. A woman (White/Caucasian) and a man (Asian/American Asian) stated that having **different priorities** from your peers makes it harder to fit in. The woman also shared that it is **hard to find partners** for group work and that sometimes being a part of the group **did not help with belonging**, as no friendship was formed. The men said that the previous work in data science did not prepare them for CS, hence the feeling of not fitting in.

Two men (Asian/Asian American and White/Caucasian) reported that sometimes they **do not feel that they fit in**. One of the stated reasons is the **highly competitive nature of CS** and, consequently, peers not wanting to aid when someone does not understand the materials, **cliques** that are being formed, or majors **looking down upon CS minors**. Additionally, **pedagogy that promotes competitiveness**, such as extra credit for first X submissions, might contribute to cliques forming and not helping the peers, hence negatively influencing the sense of belonging. Interviewees described that because computer science often has a competitive nature, students' feelings of belonging are challenged with "imposter syndrome" and the "dehumanizing feeling of rejection".
Lance: "Honestly, I don't know that I would say that I fit very well. There's a lot of ways, I guess, that you could approach that question. But, I think there's definitely ways in which sometimes I don't [don't fit in]. I think, for example, ... I think especially in the data science program, but also the computer science program people are very career-oriented, and there's definitely an idea that everyone's on this constant grind for getting internships and jobs, that I just don't enjoy engaging in. And, that's definitely something where there's this... Alongside being a computer science major, and there's separate kind of competitive atmospheres going on."

Globally, programs, clubs, supportive instructors, and peers significantly contribute to a feeling of belonging. However, the students also indicated that the feeling of belonging may be solidified by group work and a shared understanding of perseverance, which happens later in the program. Previous experience helps the student to feel "familiar" and that they belong. As students progress in the program, they begin to have more opportunities to connect in smaller or more interactive classes. Therefore, the feeling of belonging **might become embodied later in the pathway**.

Collaboration

All women and all but one man (Asian/Asian American) emphasized that working in **small groups** has been helpful. Additionally, all women and White/Caucasian men think that it is **necessary for upper-division courses**. However, the majority of women think that it is easier and more beneficial to **work independently in lower-division courses**, where the problems are relatively small. However, a woman (White/Caucasian) shared that group projects help with **making friends**, but **not until the second or third year**. A (who did not specify ethnicity/race) said she did not have an issue with the group members, and another (Hispanic/Latina) stated a preference to **choose the group members**. While one White/Caucasian man also shared that the requirement to collaborate is helpful, he added that collaboration encourages **thinking the problem through** before implementing.
Lance: "... I love to work with people. I really feel like everyone always has a different mindset and approach to a problem. I love working with other people and talking through how to do it... Usually, what we would do is sit down, talk about the problem, and before we even opened our computers to write code... and then we would sit down and kind of write our logical approach into code, and I loved that because I think through talking... so talking about something before I sit down and start coding it was incredible."

A White/Caucasian man reported that group work helps professional applications if it is surrounding **real-world problems**. Two Asian/Asian American men reported that collaboration, especially **interdisciplinary**, not only motivates the students but helps them **learn different perspectives** from working with different people.
Riley: "I think most of my experience in college were just working with teams. And I actually enjoyed that because I like working with different types of people. So when I was doing like game development, I would work with a artist, a sound designer, a writer. So that was really fun."

Orthogonally, two White/Caucasian men also **enjoy autonomy and challenge** when they get to work on a project individually. Some students mentioned that the experience would **depend on the course subject**, and others mentioned that collaboration might mean only **work independently, and compare the answers** before the submission. Additionally, they sometimes struggled **with some group members**, **interpersonal dynamics and secrecy**, and when **team members were not well-matched**. A man (Asian/American Asian) shared that he preferred **working alone** because he wanted to **make decisions**, and **not wait/synchronize with others**. Additionally, a man (White/Caucasian) reported **feeling pressured** when working in groups and also feeling **self-conscious**.

All students reported positive, neutral, and negative experiences and stated preferences for how to collaborate. It appears that the experience is influenced not only by personal preferences but also by collaboration policy, team dynamics, course content, and circumstances.

Outlook

The students emphasized the need to balance student knowledge inside of the classroom with out-of-classroom skills. Students were particularly aware that one needed to actively seek help in

their program. A student (White/Caucasian woman) noted that **independence and self-accountability** resulted in her asking for help, persevering, and succeeding.
Emma: "But I also said independent. I felt like in most of my classes... I never did any group work... It was always very independent, and that varies per professor, per quarter... And that independence also translates to, if you don't go seeking for help from the staff, or if you don't make an effort to attend office hours, you could end up very well doing the course entirely alone."

Also, another student (White/Caucasian man) felt that successful students are typically **not afraid of failure**, and can accept that none of their code would work perfectly from the start. The growth mindset and positive outlook led to this student's success.
Jacob: "[A successful students should] not be afraid to fail. And if you do fail, it shouldn't be the end of the world 'cause it happens all the time (laughs). Bug in your code, it's not a big deal."

We notice that the self-advocating, accountability, and growth mindset play a significant role in perseverance and positive perspective.

Policies and Staff Support

Most students found collaborating in small groups to be helpful (Sect *Collaboration*), however, a White/ Caucasian woman emphasized that the means and extent of collaboration need to be **defined in a (class) policy**. For example, a group thrived when they were able to brainstorm different approaches to coding a problem and bounce ideas off of each other before implementation. In contrast, collaborating felt negative when each person wrote their code and then compared answers.

Five students (mixed gender and race/ethnicity) emphasized the positive impact of having support from **program staff**, such as **advisors, teaching assistants, professors, and tutors**. One student appreciated that their university program felt **welcoming** because it was **open to students with all levels of experience**, which may counteract a possible limiting factor for underrepresented students from under-resourced middle schools and high schools. The overall notion of a welcoming program relates to program and class policies, but also pedagogy and belonging.
Riley: "... tutoring helped a lot too. If I need help on any of my homework, I would go to tutoring."
Samantha: "During that program, they brought in the career professional development office to come and talk to us. And so having spoken to someone in the career and professional development office, helped me be inclined to reach out to this office when I started, my first year, which I know a lot of students didn't do. And that's actually what helped me get an internship my first summer, which was having this connection. And so I'm glad that they brought in that office to come and talk to us and helped us with our resumes. And they also took us to trips around the area, I'm from LA, so it wasn't too much of a big thing."

Program policies, including required courses and **long prerequisite chains**, that result in slow exposure to CS classes, and classes that are **too big to connect** (to other students or instructors) resulted in negative perception. Most of the comments in this category were provided by women (all three: White/Caucasian, Hispanic/Latina, and the one who did not declare race/ethnicity) and

one man who was White/Caucasian.
Jacob:" [We should start with] SQL and Python or C++ whatever, from the very beginning and then move out from there."

Other issues included the way some professors prioritized their research, so they did not create meaningful learning experiences for the students. This links to the effects of the **Retention, Tenure, and Promotion policy** on student success.

The participants acknowledge the impactful role of program staff in the successful CS trajectory and point to the need for well-defined policies that will facilitate positive student interaction and growth.

Gender and Race/Ethnicity

All students reported that they **never felt sexism or racism**. Two men (White/ Caucasian) reported that they understand that it may be challenging to be the only person (of a certain gender or race/ethnicity) in a class. We believe that **recognizing the challenges that underrepresented students have** is not only kind and thoughtful but also a necessary step towards a more inclusive academic environment. However, many respondents were aware that some students may receive **different treatment due to gender or race/ethnicity**, with male students taking extra caution around female students for fear of offending them. A White/Caucasian woman testifies about one such experience.
Emma: "I was in a breakout room with four or five guys, and a long story short when we ended up back in a breakout room together, I got an apology from one of them for arguing with me or something in the previous breakout room, which was totally... I mean, it was a discussion . . . an apology not necessary by any means."

Additionally, one man (Asian/Asian American) related this different treatment to his feelings about the existence of implicit sexism.
Yoshi: "...my friend that I worked with the first two years of undergraduate... She's a woman. And I think just being with her in office hours, or seeing other people in classes, there's definitely the way people engaged with her is maybe a little more... it's kind of different. I think either they sort of tried to explain stuff to her more... And she's very nice about it, too.
But, there's definitely more of... Maybe people don't feel like they're equals, necessarily, like the default assumption. ... That's probably the only thing in terms of sexism... Like, there (are) some isolated incidents, obviously. Even what I just described. That's pretty isolated."

A woman (who did not declare her race/ethnicity) also noted **different treatment** among **peers** based on **gender or race/ethnicity**, due to similar groups organically gravitating towards each other. We may conclude that it may be very hard for a student to find "their place" if they are the only one in the class/cohort. Most interviewed students were aware of male-dominated classrooms, and that this may have led to an implicit "othering" of female students.

Finally, one woman (Hispanic/Latina) reported her perception that the **gender ratio within the program is improving**.

Samantha: "No, I think it was pretty good, besides there being not as many females, but it's getting better. I think throughout the years, I've seen the male-to-female ratio, it's a lot more even now than it was when I started."

A White/Caucasian man also noticed a positive trend for gender **diversity** amongst the instructors but remarked that the composition of the faculty still does not represent the student body, especially for the underrepresented populations. He perceived that the student body also lacked diversity.
Lance: "I think it'd be a little easier for people to feel more at home in a major if they saw themselves represented in the faculty, so that would've been nice, and that's something I definitely think that they can improve upon."

While the students did not report that they felt sexism or racism, they are aware of imbalances and implicit differences in treatment due to gender and race/ethnicity. We will discuss how to explore this topic in a more nuanced way in Sect. *Discussion of Findings and Method and Follow-up*.

Discussion

Trustworthiness and Rigor of Our Study

To have trustworthy and rigorous qualitative data acquisition and analysis, the researchers need to consider four main areas: credibility, transferability, dependability, and confirmability [55, 56]. In this project, credibility is supported through peer debriefing where multiple researchers read, reviewed, and analyzed data together creating investigator triangulation. There were at least two sets of eyes on each data set and four people discussing the findings and interpretations. Transferability is ensured by utilizing the thick, rich description, that consequently provides clear descriptions with supporting examples and corresponding citations. Dependability is ensured by tracking all research activity and keeping multiple versions of coding and analysis for an appropriate audit trail. Finally, confirmability was maintained by the interviewer asking multiple follow-up questions to clarify and confirm the interviewees' responses, and investigator triangulation was used.

Limitations

This is a small set of interview data with a population of convenience (towards or at the end of the CS program) that does not fully represent the students at different stages in the program or include the ones who are struggling. In the follow-up study, we plan to expand the population to the students who are in the beginning and middle of the program, and to attempt to find those who are struggling or maybe even who left the program. We will utilize the information about potential "weeder" courses from our quantitative analysis for the recruitment of interviewees.

Also, the race/ethnicity, gender identity, or first-generation status of the interviewees was limited, which we will address by selecting a larger number of more diverse participants, making sure that the voices of those typically minoritized in computer science [44] (such as Latinx, Transgender, Women, and African American individuals) are heard. Moreover, we want to expand the qualitative study to include socioeconomic status (SES) and facilitate the data analysis for

intersectionality. We will include SES data in the initial demographic data collection that all study candidates provide before being selected. We will also update the questions to explore students' perceptions of opportunities and barriers that are related to funding. With a wider set of diverse students, we expect to obtain new findings.

Nevertheless, running the study with the observed population (a small group of successful students) resulted in data saturation: no new topics emerged towards the end of individual interviews or with the new interviewees toward the end of the interview process. Finally, we do not present a statistical analysis of our findings based on gender, race/ethnicity, or institution due to the sample size. We only report the findings as observed, and note that our conclusions are relevant in the context of the interviewed population.

Findings Related to Institutional Structures

The students from all institutions participated enthusiastically and answered all questions. Before the larger follow-up study, we do not want to draw conclusions regarding the themes we discovered or their magnitude, but report the observations. All the students, irrespective of the institution, had very different previous experiences (Sect. *Prior Experience*) and it was unrelated to the institution. The women reporting on the importance of programs and clubs (Sect. *Programs and Clubs*) were from Institutions 2 and 3. We are curious to explore to which extent the outreach activities are related to the external funding or to SES status of the students that attend each institution. The students from two larger universities provided more details on pedagogy and mentoring (Sect. *Pedagogy and Mentoring*), and we wonder if that might have to do with the size of the student body and the number of sections for the same course and, possibly, exposure to many different instructors.

All institutions had one or more students reporting a strong feeling of belonging (Sect. *Belonging*). Two students who reported that they sometimes felt that they did not fit in were from two larger universities. The reasons may point to the program size and related admissions or class policies that lead to the students feeling unsure of their belonging in the competitive environment. Additionally, the experience with collaborations (Sect. *Collaboration*) was across the spectrum, and we observe that there are many factors (policies, class "type", individual preferences, collaborators, etc.) that affect their perception. The student's experiences could be used to guide policies regarding collaboration. Even though one might think that the outlook (Sect. *Outlook*) is a deeply personal trait, there might be something to be done about it on the institutional level, such as offering continuing seminars on "how to navigate university". So far, students from two larger universities shared details about their outlook.

Overall, the students from all institutions shared positives about the support provided by the instructor and the staff (Sect. *Limitations*). The staff and the instructors from both larger and smaller institutions were praised for their role in students' pathway to success. The students from all three institutions shared nuanced views about the impact of gender and race/ethnicity (Sect. *Gender and Race/Ethnicity*) on one's experience in the program. The students from a large public institution shared a bit more details, whereas the students from the other two institutions showed awareness of and compassion towards the potential issues.

Discussion of Findings and Method and Follow-up

An interesting observation warranting further investigation is that many of the students had overall *positive outlook* about many discovered themes. The positive outlook might have contributed to the *sense of belonging* but it also might be that it is a *characteristic* of the interviewed students in this study, who were *all successful*. The factors contributing to such an outlook are worthwhile to investigate further with the broader student population in follow-up studies.

Some of the findings align with the surveyed literature, and sometimes we see nuanced views and some emerging topics that may not explicitly correlate with gender or race/ethnicity. For example, it is well-known that belonging is an important factor in retention, and hence student success [31]. Our study confirms the impact of programs, clubs, pedagogy, and supportive staff on creating a sense of belonging. But we also found that the feeling of belonging might become embodied later in the pathway, due to a shared sense of persistence and more opportunities for collaborative work. As attrition may happen from the very beginning of the program, one idea is to provide more opportunities for peer support and community building early in the program through bridge programs or clubs based on interest rather than demographics or providing shared space for studying. We also found that early exposure to CS elevated both interest and sense of belonging, so the CS programs might want to implement early and proactive advising to level the playing field for minoritized students. We would also like to explore the mechanisms needed for developing a mindset for proactively reaching out for help/advice and a growth mindset. In this context, we would like to investigate the role of support from faculty, staff, or programs that might help the students develop those scholarly attributes.

Another interesting observation is that our participants reported that they did not experience any explicit sexism or racism. We wonder if the formulation of question nine might have been the issue, as ”sexism” and ”racism” are very strong and emotional words. We are considering a change of verbiage to ”different treatment or opportunities due to genre or race/ethnicity” to open the conversations toward detailed and delicate experiences of different populations. Another hypothesis is that there may be a normalization effect. For example, men and women might notice that there are very few women in CS, but they might not perceive it as an issue because they are used to it from everyday situations. We are also wondering if the already somewhat gender-diverse population teaching CS in the observed institutions might have played a role in our findings.

Some questions remain whether issues related to gender, race/ethnicity, or SES status, are as much of an issue compared to other issues such as competitiveness, non-gender related cliques, or pedagogy. Since we interviewed successful students, it is possible that they did not emphasize those issues related to gender, race/ethnicity, or SES status. It could also be the case that the interview questions were not deep enough to bring out other underlying issues regarding gender, race/ethnicity, and SES.

Finally, three individuals were part of a focus group rather than individual interviews and they reported no preference between focus groups and individual interviews. They did not report any discomfort and although we acknowledge that they may have been influenced by each other, we

found a synergistic effect of the focus groups. We believe that the interactions among the participants in the focus group resulted in the responses and findings that we might not get from individual interviews. Moreover, we also found that the interaction between the participants brought up the responses faster i.e. within the fewer questions. The responses to the last few questions have already bubbled up, and neither of the participants had anything to add when asked for additional comments. We also acknowledge that gender might have been a contributing factor to the focus group dynamic and we are unsure if the dynamic, hence the findings, might be different if the focus group consisted of men. Finally, all students also reported that the gender and race/ethnicity of the interviewer do not matter, but that they would prefer an interviewer who is not from the same institution. One student mentioned that they are unsure if, in general, a participant might experience discomfort while talking about gender issues based on the gender identity of the interviewer.

Conclusion

The study protocol allowed our research team to examine students' lived experiences in CS and brought several issues to light. Early exposure, a sense of belonging, support from the instructors and staff, a positive collaborative environment, and peer support are positive driving forces toward student success. The results shed light on potential policies and initiatives for institutions to promote. For example, faculty professional development to develop engaging pedagogy might be an important strand for an institution to explore. In addition, initiatives for early exposure and cohort building may be a worthwhile investment for institutions to make. Institutional outreach coordinated with high schools that strongly encourages the students to participate in a bridge program would increase a sense of preparedness and belonging.

Our future work will continue to explore factors leading to positive and negative experiences in CS. This will be done through more interviews and focus groups with a larger, more diverse group of students and with particular attention to the recruitment of students to participate in the study who represent different experiences and backgrounds. In particular, we also are interested in locating students who are at risk of dropping out or who have already dropped out as they may reveal reasons and circumstances for attrition.

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