

Women of Color in Computing Graduate Education: Structural Supports and Navigation Strategies for a Hostile Culture

Nuria Jaumot-Pascual
TERC
Cambridge, MA
nuria_jaumot-pascual@terc.edu

Christina B. Silva
TERC
Cambridge, MA
christina_silva@terc.edu

Audrey Martínez-Gudapakkam
TERC
Cambridge, MA
audrey_martinez-
gudapakkam@terc.edu

Maria Ong
TERC
Cambridge, MA
maria_ong@terc.edu

Abstract—This paper presents themes that emerge from empirical literature on women of color (WOC) in computer science (CS) graduate education. We ask, *According to the literature, what factors affect the experiences, participation, and advancement of WOC in CS graduate degrees?* The findings are drawn from a subset of literature on graduate education from our National Science Foundation-funded project, *Literature Analysis and Synthesis of Women of Color in Technology and Computing*. Findings of on-campus social supports include student support groups and peers who provided community, navigation strategies, and motivation to succeed. Family and friends also provided recognition and encouragement. Students attending Historically Black Colleges and Universities reported that their schools provided them with structural support through recognition and investment in their potential. Findings of barriers include a sense of isolation, as well as professors and male classmates creating a culture of hostility and exclusion for WOC. Despite these challenges, WOC used individual and social strategies to navigate and persist. They drew on their determination, dedication to achieving goals, and past challenges to stay motivated and succeed while also developing soft skills. They were further motivated to use their knowledge of CS as a tool to solve problems and help others. Our synthesis contributes an analysis of the social and structural supports and barriers for WOC in the understudied field of CS graduate education. This research will increase knowledge about success strategies to retain women of color with advanced CS degrees to fill the United States’ technological workforce needs.

Index Terms—Computer science education, graduate education, women of color, meta-synthesis

I. INTRODUCTION

Some of the fastest growing occupations in the United States are within the field of computing and technology

(CS/tech) and offer promising job security and high salaries, especially for those with graduate degrees [1]. However, women of color (WOC) in the U.S. are significantly underrepresented in CS/tech graduate education relative to their presence in the U.S. population as a whole. In 2018, WOC represented 21.2% of the population, while representing 16.8% of CS/tech masters and 8.5% doctorates in the same year [2, 3]. According to the data, women who are Black/African American, Hispanic/Latinx, American Indian and Alaska Native, and Native Hawaiian and Pacific Islander are especially underrepresented (see Table I). The only exceptions are Asian/Asian American women, who are not underrepresented in CS/tech graduate education. However, once in the workforce, they are less likely to be in positions of leadership than White women [1].

TABLE I. Representation of Women of Color in the U.S. Population and Earned Graduate Degrees in Computer Science (2018)^a.

	% of Total Population	% Masters	% Doctorates
Women of Color	21.2%	16.8%	8.5%
Black/African American	6.7%	4.8%	2%
Hispanic/Latinx	9.2%	2.2%	1.8%
American Indian & Alaska Native	0.4%	0.1%	D ^b
Native Hawaiian & Pacific Islander	0.1%	n/d ^c	0.0%
Asian/Asian American	3%	6.2%	4.7%

- a. Elaborated with data from the U.S. Census Bureau [2] and the National Science Foundation [3].
 b. D = suppressed to avoid disclosure of confidential information.
 c. n/d = data not available because data on Pacific Islanders was reported as part of the Asian classification.

We subscribe to McGee’s view that the severe underrepresentation of WOC in STEM, and especially in CS/tech, is because the field was designed to attract “White men who are heterosexual, abled-bodied, Christian or atheist, [and] middle-class and above” [4, p. 634] and has thus created a culture that is hostile to those who deviate from the criteria. We further view the low representation of WOC graduate students in CS/tech as an important equity issue, where students of color (and particularly WOC) are not offered the same opportunities. As McGee indicated, “Traditionally marketed as a competitive and meritocratic field, research has shown that there is more bias in STEM professions than their non-STEM counterparts” [4, p. 635], with lack of diversity being an even greater problem at the graduate level than at the undergraduate level. Moreover, most students “attend graduate programs with hopes of emerging as leaders in their academic or professional fields” [5, p. 2]; yet, with a small number of WOC as graduate students in CS/tech, even fewer will reach leadership positions. Their small numbers in graduate school can translate to a dearth of WOC faculty, which can have snowballing effects for younger generations in the field in terms of social isolation and lack of positive role models [6,7]. Progress to broaden participation in CS/tech and other STEM disciplines has been exceedingly slow, in spite of the millions of dollars invested by the National Science Foundation and other national-level organizations [8]. Therefore, institutions of higher education (IHEs) must take local responsibility to dismantle the structural racism and sexism that permeate their cultures and practices in order to achieve environments that support, value, and celebrate the contributions of underrepresented and racially minoritized people, and particularly WOC in CS/tech graduate education.

II. CONCEPTUAL FRAMEWORK

The research shows that individuals in STEM who live at the intersection of two non-dominant identities, such as being women and non-White, tend to experience additional challenges compared to those experienced by White women or men of color [4, 9]. In the context of CS/tech higher education, ignoring intersectionality can lead to issues of attrition [10]. Unfortunately, existing empirical research has largely sidestepped the study of the experiences of WOC in CS graduate education, mostly focusing on their undergraduate CS experiences (e.g., [11, 12]); graduate students of color (both men and women) in CS and engineering (e.g., [13]); WOC graduate students in general STEM (e.g., [14; 8]); or African American women transitioning from undergraduate programs in historically Black colleges and universities (HBCUs) to graduate programs in STEM in predominantly White institutions (PWIs) (e.g., [15]). Across these related bodies of literature, consistent themes arise, including perceived messages of not belonging; negative interactions with faculty and peers; experiences of invisibility and hypervisibility; feelings of exclusion, isolation, or being tokenized; experiences of impostor phenomenon; and exhaustion from the emotional toll from coping with these stressors. Joseph’s [15] study additionally described the chilly climate experienced by Black

women in STEM doctoral programs at PWIs and a series of strategies for success that ranged from resistance and navigation strategies (e.g., refusing to give up, seeking mentors), to strategies directed towards their departments (e.g., asking faculty for help, becoming involved in departmental activities), to social strategies (e.g., seeking safe spaces on and off campus). These themes of struggle and strategies for success were resonant with findings in the present literature synthesis, discussed below.

Ong, Jaumot-Pascual, and Ko [16] adapted the psychology term *social pain* to refer to a set of experiences related to rejection and a lack of belonging in STEM. “When a human experiences social pain—including rejection, feeling left out, or feeling like one does not belong—it triggers a neural reaction that may be analogous to a reaction to physical pain. A physiological alarm goes off, interrupts current tasks, and focuses attention on mitigating the pain” [16, p. 595]. As a result, social pain diverts cognitive resources toward managing the social situation and away from other areas, such as engaging in graduate education. The four types of social pain identified by Ong et al. included being the only one, being made invisible, stereotype threat and being spotlighted, and discrimination and harassment. These overlap with the areas identified by the related literature described above.

The present synthesis study is unique as it addresses the dearth of published literature and synthesizes nearly 20 years of empirical research on the experiences and factors that hinder and support WOC’s persistence in the CS/tech graduate education through the lens of social pain. We also provide recommendations for leaders in CS/tech graduate education and research. This synthesis study addresses the research question, *According to the literature from the last two decades, what factors does the existing literature find that affect the experiences, participation, and advancement of WOC in CS graduate degrees?*

III. METHODS

We provide an overview of the methods our team used to search, select, and analyze the appropriate literature for this synthesis. For a more detailed explanation of our methods, please refer to Ong, Jaumot-Pascual, and Ko [16].

A. Stage 1: Pre-Search & Start Set

Before the identification of relevant empirical research literature, we conducted the pre-search activities established and detailed in our previous synthesis study [16].

Pre-search activities. We first created a list of criteria to select studies to include in the synthesis. We sought empirical studies published between 1999 and 2019 (when our search phase ended) that reported research on WOC in CS graduate education and applied a *quality appraisal criteria*, which determined basic methodological elements necessary for a research study’s inclusion.

We conducted a comparative test of 16 search engines to find the best tools for our search process. Once the test narrowed the engines down to seven, we learned their Boolean

rules to do our searches. We created a list of search terms matching the content fields in our criteria and built “search strings” by creating all the possible combinations of our search terms using the engines’ Boolean rules.

The Start Set. We then proceeded to establish the start set, which is the initial group of full-text primary research reports that become the basis for the subsequent snowballing searches. We entered the search strings and publication range into the search engines and conducted the searches. Our team then identified which references to keep by applying two filters and a quality appraisal. In Filter 1, we sifted through titles and abstracts for a first yield of the literature. In Filter 2, we read the remaining full pieces to ascertain that they fulfilled the criteria. In the quality appraisal, we determined whether each study included the preselected basic elements of a research study. The studies that remained after the three screening steps became part of the start set. Throughout these steps, the literature was tracked and catalogued.

B. Stage 2: Forward and Backward Snowballing

Forward and backward snowballing [17] were used to identify additional literature. *Forward snowballing* involved finding the literature that cites each of the pieces in the start set, which results in more recent pieces. Google Scholar’s “Cited by” feature is the tool we used for this purpose. *Backward snowballing* involved reviewing literature that was cited in the bibliographies of the pieces in the start set, thus resulting in older literature. We then repeated the same three screening steps and tracking and cataloguing processes described above. The start set, combined with snowballing, resulted in a total of eleven pieces for this synthesis (see Table II).

TABLE II. Empirical Research on WOC in CS/Tech Graduate Education Included in the Synthesis.

Author/s and year	Literature format	Method. stance	STEM field	Race/ ethnicity and gender descriptors ^a
Ashford (2016)	Dissertation	Qualitative	Computing disciplines	African American women
Charleston, George, Jackson, Berhanu & Amechi (2014)	Peer reviewed journal article	Qualitative	Computer science	African American women
Herling (2011)	Dissertation	Qualitative	Computer science	Hispanic women
Hodari, Ong, Ko & Kachhaf (2014)	Conference proceedings	Qualitative	Computer science	African American/ Black, Asian American, Latina, White, Arab, Native American, mixed race women
Hodari, Ong, Ko & Smith (2015)	Conference proceedings	Qualitative	Computing disciplines	Asian American, Latina, Black women
Hodari, Ong, Ko & Smith (2016)	Peer reviewed journal article	Qualitative	Computer science	Asian American, Black, Latina, Native American, Arab women
Middleton (2015)	Dissertation	Mixed methods	Information technology	African American women
Murray-Thomas (2018)	Dissertation	Qualitative	STEM (e.g., computer science, veterinary science, environ. sciences)	Black females
Tancredi-Brice Agbenyega (2018)	Dissertation	Qualitative	Computer sciences & engineering	Latina/ Hispanic women
Thomas, Joseph, Williams, & Burge (2018)	Conference proceedings	Qualitative	Computer science	Black women
Tran (2011)	Dissertation	Qualitative	STEM (e.g., computer science, biological sciences, chemical science)	African Americans, Latinas/os, and American Indians men and women

a. Descriptors listed originate from the authors’ respective pieces of literature.

C. Stage 3: Iterative Analysis

Establish codebook. Next, we created a codebook through a hybrid approach to coding in thematic analysis [18], that used both deductive [19] and inductive [20], [21] coding. We then brought together the two sets of codes to consolidate them in a single codebook, which was treated as a living document, periodically updated and refined by team consensus [20], [21].

Analysis steps. We analyzed the resulting pieces of scholarship through an iterative analysis based on team check-ins and consensus to solve coding disagreements and to achieve consistency across the team. Analysis included the following steps: (1) creating analytical memos for each of the studies, which synthesized their main findings; (2) using the codebook to code the memos; (3) conducting thematic analysis to create the synthesis meta-findings; and (4) discussing findings through the lens of the theory in our conceptual framework.

D. Limitations

This synthesis' limitations are linked to the methodological choices made by our team and the limitations of the studies included. Our methodological choices, such as the criteria to select which studies fulfilled our quality appraisal criteria, may have excluded studies that could have contributed valuable findings to the synthesis.

E. Researchers' biases

The four authors of this synthesis identify as women who are minoritized due to their intersecting identities and/or their national origins/cultural backgrounds. As such, the team is interested in highlighting the experiences of WOC in CS/tech and diversifying CS/tech as social justice issues that will help in providing WOC with access to careers with growth and high pay potentials.

IV. FINDINGS

Below, we describe three major themes found in our synthesis of literature on graduate women of color in CS: (A) CS as a culture of exclusion of exclusion and hostility; (B) social supports that provide resources and motivation for persistence; and (C) additional strategies for navigation and persistence. It is important to note that, due to the limitations of space, in each thematic section, we provide only a few illustrative examples of the experiences of women of color in graduate computing education, which are representative of many others not cited here.

A. A Culture of Exclusion and Hostility

Throughout the synthesis literature, it was evident that WOC who pursue CS in graduate school often face barriers that hinder their ability to persist and succeed in CS. WOC often experienced a culture of exclusion and hostility which manifested in various ways. This included unwelcoming environments, exclusion, and isolation from classmates who were predominantly White male peers [22], [23], [24], [25]. These elements were exacerbated by the absence of institutional support for WOC and members of other minoritized groups [23]. As WOC navigated this culture of exclusion and hostility,

they encountered various stereotypes that contributed to feelings of not belonging and social pain. The major contributors (or enforcers) of these negative experiences were professors who, at times, publicly humiliated and expressed hostile attitudes towards WOC in front of other classmates [22], [23], [25], [26]. For example, Maddie, an Asian American woman pursuing her Ph.D. in CS in Hodari, Ong, Ko, and Kachchaf's [26] study, described how her graduate advisor doubted her scientific abilities, and then stopped speaking to her altogether.

[After] an unsuccessful presentation, [Maddie's] advisor expressed extreme disappointment in her, saying he had "serious doubts about [her] scientific abilities." Furthermore, rather than discuss Maddie's performance, he stopped communicating with her for months. Maddie explained the harmful effect this had on her motivation to pursue computing: "It was kind of, unfortunately, a defining moment which probably pushed me away from science... I eventually got a thesis and defended [but] we never really spoke about that again... He said he was relieved to know that I wasn't completely clueless, but it was really upsetting, because his first assumption was that I was clueless." (p. 87)

In Ashford's [22] study on African American women who had obtained Ph.Ds. in a computing discipline, one of the participants recounted how a White male professor in her master's program told her she wasn't "creative or intelligent enough to get a Ph.D." but was "an excellent affirmative action candidate" (p. 116).

The hostile conduct by professors did not stop at just words but, for some, included physical assaults and threats. One of Ashford's [22] participants, an African American woman named Susan, disclosed how a White male professor physically assaulted her, during a class discussion she was leading, by hitting her over the head with a stack of papers in front of the entire class. Susan also shared how there would be periodic appearances of the Ku Klux Klan (KKK) at her school's campus, contributing further to a heightened presence of racism on campus as she pursued her CS Ph.D.

Now we were in [the deep South]. It was already hard enough to come to school every day with the KKK out on the lawn. Then, you're going [to hit me on the head with a stack of papers]. That was just so demeaning. You don't do that to adults. [He treated me] like I was just a dog ... I do not know how in the world I even continued. I was completely caught off guard. I would have never expected anything like that. Of course, I made it through the class. Then right after the class, I cried a flood of tears. (p. 120)

Experiences of a culture of exclusion and hostility were not limited to interactions with professors. The literature shows that

peers also played key roles. Participants in Charleston, George, Jackson, Berhanu, and Amechi's [23] study shared how Black women in CS had to contend with negative stereotypes related to their academic and intellectual abilities. One participant in their study declared, "There are often assumptions that I am supposed to act a certain way because I am a Black woman" [23, p. 171]. The researchers added of this participant, "She continued to describe how she felt others expected her to get upset or defiant when events would occur that were not particularly in her favor" [23, p. 171]. In this study [23] and others [22], [24], [26], [28], researchers noted that participants widely shared experiences of isolation and having their academic competence questioned.

Beyond racial stereotyping, WOC also experienced exclusion due to not fitting the nerd stereotype that is often associated with men pursuing CS [24]. In Herling's [24] study on Hispanic women in CS, participants discussed "not fitting in because they had different interests and did not speak the same 'language' as their male classmates" [24, p. 65]. These participants could not relate to their male peers' humor or taste in gaming, often making it difficult to feel like they belonged or to have conversations with their male peers.

B. Social and Structural Supports

Despite experiencing a culture of exclusion and hostility, WOC were able to find social and structural supports that helped them persist throughout their CS graduate education. Instances of social support in the literature arose in terms of peer groups and CS and STEM diversity conferences [24], [26], [27], [28], [29]. For example, in Herling's [24] study of Hispanic women in computing, the majority of participants reported that they had actively participated in Latinas in Computing, a national organization that hosts annual conferences and virtual support groups that enable Latinas to interact with and support one other. Older peers also helped inspire some WOC to pursue graduate school, as was the case for Nikki, a Black woman pursuing an advanced degree in CS in Murray-Thomas's study [29]. Nikki recounted how her peer network motivated her to because she wanted to be a part of the same community as them.

I have friends that have advanced degrees. ... (I) just wanted to be a part of that community. It was just set in my mind to; this is what I want to do. This is what I have to do. If it meant sacrificing, not going to something, that's what I had to do. ... With me doing it, it would get me a better job. Not necessarily the case, but that was my mindset. That it would advance me in my career. (p. 73)

Mentors and role models also played a significant role in WOC CS graduate students lives as they navigated their program [26], [27], [28]. In Hodari and colleagues' study [26], Hailey, an Arab American graduate student in information technology who self-identified as a WOC, described how role models helped her network within her field at an annual

diversity conference in computing and encouraged her to succeed:

I love the social aspect of [the conference]. I love how amazingly easy to talk to everybody is, and the ones who are high up understand that these students are in need to network and need to be pushed up and stuff. So they don't have a lot of expectations as to like ... it's not like an expectation. It's more like, "I'm here to help you so just let me know how I can do that" sort of attitude. [p. 87]

In our synthesis literature, a few instances of structural support appeared in the form of mentoring by senior professionals [27], [28]. In a study by Hodari, Ong, Ko, and Smith [27], Georgette, a Latina professional in computing, recounted how during her Ph.D. program, she had lunch with a senior and well-respected professor who disclosed that he did not make tenure. Despite sharing a story of failure, Georgette valued his honesty because it gave her courage to see that she could have an impact on lives even if her experiences were not always linked to success:

I thought, "If he didn't make tenure and he's been as successful as he can, then if I don't make tenure, I'm going to be okay, And if I don't make tenure, maybe it's because that wasn't the right place for me and the good Lord above wanted me to go elsewhere." And that was wonderful because I was like, "It's okay to fail." So that's really empowering. It's these anecdotes as people are sharing their experiences that enable us to have courage to try things. (p. 3)

In a similar way, Thomas, Joseph, Williams, and Burge's [28] participant, Beverly, described how her mentor and her dissertation chair, recognized her intersecting identities as a Black female Ph.D. student and connected her with various opportunities and served as her advocate during her Ph.D. studies.

When I met her [dissertation chair], it was an instant connection and synergy... [S]he also recognized I am and was a black female ... And that quietly set her apart for me and that she would recognize me as a complete person, a black female that was her student. And she has been [an] advocate then and ever since, selflessly, from helping me find the opportunities that were best for me. Whether it was the Graduate Research Fellowship award or the right research experiences in her lab, and now as a mentor in my later career. (pp. 6-7)

We anticipated finding literature describing structural supports in the form of departmental or institutional actions to support women of color graduate students, but we were surprised to find very few works addressing this topic, apart from one study on HBCUs. HBCUs were found to provide

caring and supporting environments that invested in students [29]. For Mary, a participant in Murray-Thomas' [29] work, attending an HBCU gave her access to a "warm, caring, and supportive" graduate environment, where "professors saw her potential and provided the encouragement and support that she did not receive at home. They pushed her to finish" (p. 87). More research is needed to identify the role of structural supports in the persistence of WOC graduate students in CS at HBCUs, other minority-serving institutions, and PWIs.

C. *Strategies for Navigation and Resistance*

A final theme that arose in the literature is how WOC used several strategies to navigate and resist the culture of exclusion and hostility they encountered in their CS graduate education. Their desire, ambitions, and expectations for a better life helped them persist and complete their graduate program [22], [25], [29], [30]. Similarly, one African American woman in Middleton's [30] study shared how her own ambition and determination motivated her to pursue her master's degree:

It was just ambition itself ... I was the first in my family to get a master's degree ... I wanted to be successful. I wanted to have a career, something I could be proud of. I wanted to make my mom proud. I've learned just over the years growing up that, you know, that I have to do well in school ... it just kind of motivated me. (p. 107)

The desire to succeed was also apparent in participants in Ashford's [22] study. Ashford described how three African American women resisted the negative stereotypes imposed on them by White male graduate professors. For example, Bianca, who was pursuing her masters at the time, had a professor who told her and other African American graduate students that they were not Ph.D. material. Despite being discouraged, Bianca felt determined to complete her masters, and afterwards pursued a Ph.D. and became an Associate Professor in CS. Jasmine, an African American woman in a Computer Science Ph.D. program in Tran's [25] study, recounted that during an undergraduate internship, she learned from her boss that, in order to be respected for her analytic thinking and to have a front-row seat in company decision-making, Jasmine needed to obtain a doctorate. Instead of discouraging her, this realization motivated her to pursue the degree.

WOC also used the development of nontechnical/soft skills as a way to navigate their graduate education [27], [31]. Hodari and colleagues [27], [31] identified that soft skills, such as communication and taking the initiative, were used as a strategy to persist. Good communication skills also gave Sadie, a Native American doctoral student in CS from Hodari, Ong, Ko, and Smith's [31] work, the ability to build and strengthen her relationship with her advisor and their understanding of the perspectives that she brought to their work:

It's been this process of learning how to communicate most effectively with him. ... That has taken effort to get

him to consciously think about, as a Native American woman, this is how I would think about it, but as a graduate student, this is how I think about it. Then, as a cultural ambassador, this is how I think about it. We went through this whole year of that process where I was like, "Yo, dude, time out. We have to work on your Navajo etiquette." (p. 65)

The literature also revealed that WOC employed multiple ways of giving back as a means to persist in their CS graduate studies. These activities included mentoring, creating safe spaces or counterspaces [see 32] such as student support groups, serving on committees to support students of color, volunteering or working with young WOC, and focusing their dissertation research to address challenges experienced by communities of color and young WOC [24], [31]. One illustrative example is a participant in Herling's study, Gracia, a Hispanic woman who holds a Ph.D. in computer science and engineering, formed her own student group for Hispanic students pursuing Ph.Ds. because she understood how helpful it was for her to have a counterspace when she was in her doctoral program [24]. Another example appears in Hodari and colleagues' [31] study. Jade, a Black Ph.D. student in computing, discussed how she used her own experiences to support her dissertation work that focused on helping those who, like her cousin, had difficulties with reading:

I want my dissertation work to be in the area of reading. I have a younger cousin who is in the fourth grade and she cannot read. Not to say that there aren't White kids who can't read but being a Black woman from an urban area this is something that I see that is a problem and I think needs to be addressed. I think being a Black woman opens my mind to problems like that that technology can help solve. Somebody else who hasn't experienced that kind of thing a lot won't see that problem and they'll go off and solve another problem leaving this huge issue that is reading that affects everybody. They might not see it the way I see it. (p. 64)

V. DISCUSSION

In this synthesis, we find that our findings map well onto the findings by McGee and colleagues [13], Wilkins-Yel and colleagues [8, 14], and Joseph [15], about the barriers people of color, and particularly WOC, experience in STEM graduate education. Our findings also map well onto the social pain construct described by Ong and colleagues [16]. For the sake of brevity, we will only highlight a few ways in which our synthesis findings align with the existing literature. For example, our finding regarding CS graduate education's culture of exclusion and hostility [22], [23], [24] connects with Joseph's [15] description of PWIs' chilly culture and the sources of four types of social pain for women of color in engineering, as described by Ong and colleagues [16].

Our synthesis identified mentoring, peer networks, and participation in professional organizations as social supports for

WOC to navigate CS graduate studies. These findings align with the agentic strategies suggested and enacted by participants in Wilkins and colleagues' [8] study. They recommended establishing a trustworthy support network composed of mentors, peers, professional groups for women and/or people of color, and others who could provide safe spaces to share their struggles and opportunities for growth. At the same time, we want to echo McGee's [4] caution toward mentoring, as it "misidentifies, minimizes, or downplays [underrepresented minority] student's plight in STEM participation" (p. 637) by suggesting the students' inadequacy to succeed in STEM. She cautions that a focus on mentoring as a key solution to WOC's underrepresentation attributes their negative academic experiences and outcomes to internal causes instead of the external, structural barriers they too often face.

WOC's navigational strategies identified in the synthesis also align well with those described by Ong and colleagues [16] such as advocating for themselves. For example, our synthesis found that WOC tapped into their aspirations for a better life to resist and navigate challenges in CS graduate education [22], [29], [30]. This corresponds to Joseph's [15] internal resilience strategies such as refusing to give up.

Our synthesis identified giving back as an important element for persistence, which resonated with findings of Ong and colleagues [16]. They defined giving back as a navigation strategy that supported WOC's science identity development and served as a motivation for persistence. Similarly, in this synthesis, we found that WOC used their personal experiences to help their communities more effectively, which in turn was a motivation to persist in their CS graduate studies [27], [31].

VI. RECOMMENDATIONS

The following recommendations for IHEs and for future research stem from the findings from this synthesis. IHEs have the responsibility to create environments where WOC have the opportunity to succeed. Thus, IHEs should first focus on prioritizing bringing them into their CS programs by conducting targeted recruitment efforts [33]. WOC already in IHEs can have a key role in attracting others like them; thus, they need to be supported in their efforts to diversify CS [26], [27]. IHEs should hire more faculty from underrepresented backgrounds, and particularly WOC, so that WOC students can see themselves represented [23], [24]. IHEs should also provide both WOC students and faculty with formal mentoring [26], specifically mentors and role models from similar backgrounds [24] that will validate their experiences and avoid the internalization of responsibility for outcomes caused by external factors. Finally, all IHEs could emulate HBCUs in creating warm, welcoming learning environments and investing in the potential of WOC [29].

IHEs should provide WOC with social and structural supports that help them navigate and succeed in computing graduate studies. Faculty and staff should receive trainings, connected to their performance evaluations, that address racism, sexism, and other -isms that contribute to the hostile culture of CS [22], [23]. Departments should implement policies that ensure full inclusion [26]. Departments should

encourage the use of culturally relevant pedagogy in CS courses [22] and the use of real-world examples and experiential learning opportunities [24]. Departments also need to create environments through formal and informal means where WOC are acknowledged and integrated as part of the social fabric, such as creating opportunities for mentoring [26]. Additionally, departments must invest in professional development that teaches faculty and staff how to support and serve as a mentor for WOC. Finally, WOC need structural and financial support to participate in counterspaces where they can support each other [22], [23], [29].

More research on WOC graduate students in CS is needed in the following areas: the role of altruism and giving back in persistence [33]; other factors related to persistence [22], [23]; and experiences during educational transition points, such as undergraduate to graduate school and masters programs to doctoral programs [22]. Given the key role of HBCUs in the training of computer scientists of color, it is worth exploring topics such as the differences in persistence factors for WOC between PWIs and HBCUs [29]; the role of Black faculty in WOC's persistence [22]; and the strategies HBCUs use for the development and support of their students [29]. Furthermore, more research must be conducted on how IHEs, specifically members of faculty and staff, can support WOC graduate students' persistence in CS, such as through mentorship. Currently, there is little research on how IHEs, particularly those that are PWIs, can, or do, specifically support WOC's persistence in graduate computing education. While more research is needed on WOC graduate students overall, studies on Asian American, Latinx, Native women in CS graduate education students are especially needed.

ACKNOWLEDGMENTS

We thank Enobong (Anna) Branch, Quincy Brown, Patricia Garcia, and Katie Yao for their support in the development of project material used in this paper. Material for this project is based upon work supported by the National Science Foundation under Grant No. 1760845. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

- [1] F. McAlear, A. Scott, K. Scott, and S. Weiss (2018) Data brief: women of color in computing. [Online]. Available: <http://wocincomputing.org>.
- [2] U.S. Census Bureau (2018) American community survey, [Data tables]. [Online]. Available: <https://data.census.gov/cedsci/table?q=Race%20and%20Ethnicity&tid=ACSDT1Y2018.B01001I&hidePreview=false>
- [3] National Science Foundation (2018) Science and engineering degrees, by race and ethnicity of recipients: 2008-18 [Data tables]. [Online]. Available: <https://ncesdata.nsf.gov/sere/2018/>.

- [4] E. O. McGee (2020) Interrogating structural racism in STEM higher education. *Educational Researcher*, vol. 49, pp. 633-644.
- [5] J. Hiscock and K. Harris Perin (2010) Leadership insights and applications series: Graduate and professional student leadership. National Clearinghouse for Leadership Programs.
- [6] A. L. Antonio (2003) Diverse student bodies, diverse faculties. *Academe*, vol. 89, pp. 14-17.
- [7] J. T. DeCuir-Gunby, C. Grant, and B. B. Gregory (2013) Exploring career trajectories for women of color in engineering: The experiences of African American and Latina engineering professors, *Journal of Women and Minorities in Science and Engineering*, vol. 19, pp. 209-225.
- [8] K. G. Wilkins-Yel, J. Hyman, and N. O. Zounlome (2019) Linking intersectional invisibility and hypervisibility to experiences of microaggressions among graduate women of color in STEM, *Journal of Vocational Behavior*, vol. 113, pp. 51-61.
- [9] M. Ong, C. Wright, E. Espinosa, and G. Orfield (2011) Inside the double bind: A synthesis of empirical research on undergraduate and graduate women of color in science, technology, engineering, and mathematics, *Harvard Educational Review*, vol. 8, pp. 172-208.
- [10] L. Leyva, J. Massa, and D. Battey (2016) Queering engineering: A critical analysis of the gendered technical/social dualism in engineering and engineering education research, paper presented at *American Society for Engineering Education*, New Orleans, LA.
- [11] R. D. Johnson, D. L. Stone, and T. N. Phillips (2008) Relations among ethnicity, gender, beliefs, attitudes, and intention to pursue a career in information technology, *Journal of Applied Social Psychology*, vol. 38, pp. 999-1022.
- [12] L. A. Lyon (2013) Sociocultural influences on undergraduate women's entry into a computer science major, PhD dissertation, University of Washington.
- [13] E. McGee, D. Griffith, and S. Houston (2019) "I know I have to work twice as hard and hope that makes me good enough": Exploring the stress and strain of Black doctoral students in engineering and computing, *Teachers College Record*, vol. 12, n6.
- [14] K. G. Wilkins-Yel, B. L. Bernstein, J. M. Bekki, and A. J. Reed (2019) Intersectional perspectives: Interpersonal contributors to moments of doubt for graduate women of color in STEM, paper presented at 2019 CoNECD - The Collaborative Network for Engineering and Computing Diversity, Crystal City, Virginia.
- [15] J. Joseph (2012) From one culture to another: Years one and two of graduate school for African American women in the STEM fields, *International Journal of Doctoral Studies*, vol. 7, pp. 125-142.
- [16] M. Ong, N. Jaumot-Pascual, and L. T. Ko (2020) Research literature on women of color in undergraduate engineering education: A systematic thematic synthesis, *Journal of Engineering Education*, vol. 109, pp. 581-615.
- [17] C. Wohlin (2014) Guidelines for snowballing in systematic literature studies and a replication in software engineering, in *Proceedings of the 18th international conference on evaluation and assessment in software engineering*, London, England, 2014, Article 38.
- [18] J. Fereday, and E. Muir-Cochrane (2006) Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development, *International Journal of Qualitative Methods*, vol. 5, pp. 80-92.
- [19] J. A. Maxwell (1996) *Qualitative research design: An interactive approach*, Thousand Oaks, CA: Sage.
- [20] B. Glaser, and A. Strauss (1967) *The discovery of grounded theory*, Hawthorne, NY: Aldine.
- [21] J. W. Creswell (2009) *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.), Thousand Oaks, CA: Sage.
- [22] S. N. Ashford (2016) *Our counter-life herstories: The experiences of African American women faculty in U.S. computing education*, PhD dissertation, University of South Florida.
- [23] L. V. J. Charleston, P. L. George, J. F. L. Jackson, J. Berhanu, and M. H. Amechi (2014) Navigating underrepresented STEM spaces: Experiences of Black women in U.S. computing science higher education programs who actualize success, *Journal of Diversity in Higher Education*, vol. 7, pp. 166-176.
- [24] L. Herling (2011) *Hispanic women overcoming deterrents to computer science: A phenomenological study*, PhD dissertation, University of South Dakota.
- [25] M. C. Tran (2011) *How can students be scientists and still be themselves: Understanding the intersectionality of science identity and multiple social identities through graduate student experience*, PhD dissertation, University of California, Los Angeles.
- [26] A. K. Hodari, M. Ong, L. T. Ko, and R. R. Kachchaf (2014) New enactments of mentoring and activism: US women of color in computing education and careers", in *Proceedings of the tenth annual Conference on International Computing Education Research (ICER)*, pp. 83-90, Glasgow, Scotland.
- [27] A. K. Hodari, M. Ong, L. T. Ko, and J. Smith (2015) Enabling courage: Agentic strategies of women of color in computing, in *2015 Research in Equity and Sustained Participation in Engineering, Computing, and Technology (RESPECT)*, pp. 1-7, Charlotte, NC.
- [28] J. O. Thomas, N. Joseph, A. Williams, and J. Burge (2018) Speaking truth to power: Exploring the intersectional experiences of Black women in computing, in *2018 Research on Equity and Sustained Participation in Engineering, Computing, and Technology (RESPECT)*, pp. 1-8, Baltimore, MD.
- [29] L. Murray-Thomas (2018) *Jumping over hurdles to get to the finish line: Experiences influencing Black female advanced STEM degree attainment*, PhD dissertation, California State University.

- [30] K. L. Middleton (2016) Factors of influence for occupational attainment of African-American women in information technology, PhD dissertation, Robert Morris University.
- [31] A. K. Hodari, M. Ong, L. T. Ko, and J. Smith (2016) Enacting agency: The strategies of women of color in computing, *Computing in Science and Engineering*, vol. 18, pp. 58-68.
- [32] M. Ong, J. M. Smith, and L. T. Ko (2018) Counterspaces for women of color in STEM higher education: Marginal and central spaces for persistence and success, *Journal of Research in Science Teaching*, vol. 55, pp. 206-245.
- [33] E. K. Tancredi-Brice Agbenyega (2018) We are fighters': Exploring how Latinas use various forms of capital as they strive for success in STEM, PhD dissertation, Temple University.