

**Traversing the Landscape of Computer Science: A Case Study of Black Women's Identity
and Sense of Belonging in a Computer Science Doctoral Program**

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Abstract: Pathways to the professoriate for women in computer science are narrow and fraught with barriers. These obstacles are further exacerbated at the intersections of race and gender. Black women (who make up 6.4% of the U.S. population) comprise only 1.1% of computer science undergraduate degrees and < 1% of computer science PhDs. Despite these paltry numbers, one computer science PhD program may have found the combination of factors necessary to widen the pathway by engaging in strategic recruitment, developing communities of practice, and providing strong mentorship for women of color in computer science. Guided primarily by intersectionality theory, social identity theory, and landscapes of practice, this single case study explored the experiences of Black women in pursuit of their doctorate in computer science at a predominantly white institution to answer the research questions: (1) How do Black women graduate students in computer science describe their computer science identity? (2) How do landscapes of practice influence computer science identity formation or salience of Black women in a computer science graduate program? Thematic analysis of this case revealed three common themes within their experiences: *moments of impact*, *boundary spanning*, and

community residence. These themes, all of which revolve around ideas of community and support, are critical to understanding a key discovery of this study: why a sense of belonging, rather than identity salience (as much research suggests), was the best indicator of the women's persistence.

Keywords: Black women, identity, computer science, graduate studies, sense of belonging

1. Introduction

Computer science has been identified as a field with growth prospects that far outpace undergraduate production (National Academies of Sciences, Engineering, and Medicine [NASEM], 2018a). Colleges and universities simply cannot keep pace with the growth and demand of the field (NASEM, 2018a). In response, K-12 education, universities and colleges, industry, and governmental agencies alike are scrambling to determine how to address the shortage of computing professionals (Fincher and Robins, 2019; Google Inc. and Gallup Inc., 2015, 2017a,b). Research and subsequent efforts have yielded a surge in computer science enrollment; however, the distribution of participation remains skewed toward “pale and male” (NASEM, 2018a). Women's participation has been steadily on the decline and underrepresented minority (URM) participation has remained stagnant (NASEM, 2018a). While efforts have led to an increase in enrollments in computing programs nationally, they have done little to close the gap that exists between white males and virtually every other demographic (Lunn et al., 2021).

Current studies aimed at addressing this disparity have identified factors such as climate and culture in undergraduate computer science programs (Cuny and Aspray, 2001) and accessibility to quality computing curriculum prior to college (Margolis et al., 2018) as primary reasons for the lack of diversity in computer science undergraduate programs. In addition to these barriers, the computer science environment often lacks role models for women and people

of color (Gürer and Camp, 2002). This lack of role models, in the form of faculty and instructors, leads to a perpetuation of the norms, values, culture, and climate that limit interest and participation of women and people of color in computing. For these reasons, there has been an increased call to diversify the faculty and instructors in the academy. In order to answer the call, we must first understand the pathways of women of color in computer science PhD programs. This insight could not only expand who is in the professoriate, but also help administrators, graduate student recruiters, and support services better target, recruit, and support future computer science PhD students.

In an effort to understand these pathways, we selected one university department that has managed to tackle not all, but some of the barriers to success, through the creation and sustenance of a successful mentoring program designed for Black computer science doctoral students. This paper presents results from a qualitative exploration of five Black women computer science doctoral students, their experiences in a computer science PhD program, and the complexities associated with being a Black woman traversing the landscapes of race, gender, and computer science. The frameworks of social identity theory, intersectionality, and landscapes of practice provide a deeper understanding of the complex relationships between racial, gender, and disciplinary identity on graduate student persistence in computing.

2. Literature Review

Despite the global demand for computer scientists and the rise in undergraduate enrollments, representation of women and minorities on all levels is still incredibly low. Recent reports have shown that women comprise 19.9% of the computer science doctoral degrees awarded (Zweben and Bizot, 2020b); however, when the scope is narrowed to Black women (who make up 6.4% of the U.S. population), they comprise < 1% of computer science PhD degrees awarded (Lewis,

2018). This low rate of participation in computing graduate programs has sparked research to better understand this trend and the factors that contribute to it. These factors include equity challenges in graduate STEM education, and, more specifically, in the landscape of computer science.

2.1 Equity Challenges in STEM Graduate Education

Graduate programs in STEM are vital to the prominence of the nation in achieving two critical goals: (1) production of highly trained teachers and researchers of the future, and (2) contributions to technological, economic, and cultural development (Council of Graduate Schools, 2008; NASEM, 2018b). While the United States continues to lead the charge in producing advanced degrees in STEM fields, enrollment dominated by international students. Although this produces advanced degrees and contributes some diversity to the field, it brings the nation no closer to achieving diversity, equity, and inclusion of marginalized domestic populations in graduate programs (NASEM, 2018b; Perez et al., 2020).

Attrition rates in STEM graduate programs range from 38%–43% for domestic men and women with the variation largely dependent upon the discipline (Council of Graduate Schools, 2008). Couple the aforementioned structural factors with preparedness concerns in the realm of writing, and the attrition problem is further exacerbated (Berdanier and Zerbe, 2018a; Council of Graduate Schools, 2008; Guy and Boards, 2019), especially for minoritized populations.

Attrition rates for Black students from STEM graduate programs can be as high as 53% in some fields (Sowell et al., 2015). Such historic and consistent attrition rates have been the inspiration for programs and initiatives like the Alliance for Graduate Education and Professoriate, Louis Stokes Alliance for Minority Participation, the PhD Completion Project, and the Doctoral Initiative on Minority Attrition and Completion (Okahana et al., 2016, 2020; Sowell et al., 2015).

The studies conducted by these organizations confirmed that women continue to be dramatically underrepresented in STEM fields, and that less than half of Black students who enroll in a PhD programs complete (Okahana et al., 2016, 2020; Sowell et al., 2015). The most recent Survey of Earned Doctorates (National Science Foundation, National Center for Science and Engineering Statistics, 2015) reported that only 13% of all STEM doctorates conferred on U.S. citizens and permanent residents in 2014 were awarded to URM students. This is in contrast to 36% of the U.S. population between the ages of 25 and 34 who are URMs (U.S. Census Bureau, 2014).

These numbers have precipitated studies that further explored the context for a better understanding of why women and Black students are leaving the programs at disproportionately higher rates. Studies indicate that these rates are largely the result of structural and environmental factors, including lack of mentorship (Stockard et al., 2021), socialization (Rodriguez and Lehman, 2017), and diversity (Winkle-Wagner and McCoy, 2018), which ultimately lead to attrition (Berdanier and Zerbe, 2018b; Council of Graduate Schools, 2008; Lott et al., 2009). There is evidence that changes surrounding support systems can have an impact on attrition rates. Having a supportive advisor who fosters proper socialization into the research group, discipline, department, and university can be the linchpin to connecting a student's aspirations to their goal achievement—a PhD (Curry and DeBoer, 2020; McGee et al., 2016). For example, women in STEM fields have often described the male-dominated environment as being “chilly,” and “unwelcoming,” and oftentimes unbearable, leading to questions about the mental health and well-being of women doctoral students (Arnold et al., 2020; Ong, 2011; Sverdlik and Hall, 2018). Even though mental health concerns are universal with regard to all doctoral students, they are intensified by the complexities of race and gender. Women and Black students often report on the deleterious effects of what some scholars call

discouragers, often discussed in terms of isolation (Anderson-Rowland et al., 2007; Ridgeway et al., 2018), racialized and gendered interactions with advisors and peers (Miles et al., 2020), and the presence of racialized policies that adversely affect their persistence in doctoral programs (Burt et al., 2018). There are no easy solutions for these problems, but the well-being of our graduate STEM students, and the well-being of our nation, depend upon researching and creating solutions for all STEM fields.

2.2 Equity Challenges in Graduate Education in Computer Science

Unfortunately, when delving into specific STEM disciplines, we find that computer science is no exception to the rule. Much like other STEM graduate programs, computer science has struggled to shift its reliance on the international student population to domestic students (Hambrusch et al, 2020). In fact, the percentage of computer science doctoral degrees awarded to international students has been on the rise, with 2018 numbers reported at 63% (Hambrusch et al., 2020). However, the reliance on international students was abruptly disrupted in 2020 by a wealth of ambiguous and evolving executive actions by the U.S. government that limited access to student visas for U.S. universities (Executive Order 13780, 2017). These changes in the political landscape, coupled with computer science's own challenges with diversity, have resulted in graduate-level centered research with foci of recruitment and retention of more diverse populations (Cuny and Aspray, 2001). This work yielded a list of recommendations such as broadening the pool for recruitment and engagement through the pursuit of computer science graduate students from beyond the borders of traditional undergraduate computer science programs, encouraging more undergraduate women to consider graduate school, and evaluating and updating acceptance criteria to be more inclusive. Historically, admissions to computer science graduate programs were reliant on Graduate Record Examination (GRE) scores and

technical skills. But research suggests that much like the SAT, the GRE score is not always an accurate predictor of success in a graduate program (Hall et al., 2017; Moneta-Koehler et al., 2017). Likewise, shortfalls in technical prowess can often be mediated by motivation, communication skills, and social commitment (Cuny and Aspray, 2001). Congruent with research in other STEM disciplines, researchers have suggested that retention efforts should be directed more deliberately toward proper mentoring, community development, and cultural shifts within computer science departments (Cuny and Aspray, 2001). The culture in many computer science graduate programs generally accepts and promotes behaviors of “fierce single-mindedness of purpose, competitiveness, and aggressive assertiveness” that are abhorrent to those who subscribe to a more collectivistic perspective, as well as those potential graduate students who want or have families (Cuny and Aspray, 2001, p. 12).

Most research on the diversification of computer science has focused on women and people of color, but primarily as exclusive populations. Research on racial and ethnic populations in computer science has largely explored themes related to accessibility and engagement strategies (Sax et al., 2017). However, scholars have recently begun to challenge the aggregation of Black women in computer science into exclusively racial or gendered studies and instead push the community to take an intersectional approach, taking into consideration their racial, gendered, and disciplinary identities (Rodriguez and Lehman, 2017). The argument is that people who are stratified across multiple social identities are often relegated to the margins or represented as asterisks in research because of their underrepresentation (Rodriguez and Lehman, 2017). Such a practice essentially ignores their experiences because their small numbers often do not lend themselves to statistical significance (Margolis et al., 2010; McGrath Cohoon and Aspray, 2013). As such, the existing body of work omits or silences those at the intersections.

The studies focused purely on Black or African American women have begun to demonstrate that neither women nor people of color can be studied under the assumption that they are a monolith (Jackson et al., 2013). While Black women have similar experiences and pathways to computer science as their near peers (people of color or women), they also have experiences unique to being both Black and a woman (Ross et al., 2020; Burge and Suarez, 2005).

Black women in engineering and computer science doctoral programs do not simply suffer isolation; they are often the only Black woman in their program, rendering them desired as the *tokens* who serve on all committees, and the (often) unwilling stars of marketing materials, while simultaneously being isolated through the practice of negotiating the norms and values in the department (Artis et al., 2018). They also often carry the added cognitive burden of *code-switching* due to the need to separate their more casual selves from the context of the graduate program (Artis et al., 2018). Likewise, Black women often carry two more additional burdens sometimes referred to as “support/bigger than me”: (1) the burden of seeking out a variety of support groups other than the ones the existing structures offer, and (2) the burden of viewing their successes or failures as being those of the larger Black woman community (Artis et al., 2018). Similar to women in general, Black women also combat persistent discouragement and the accumulation of microaggressions from their peers, advisors, faculty, staff, and administrators (Lewis, 2018). These microaggressions result in self-doubt, beliefs related to imposter syndrome, and the constant negotiation of belongingness and worthiness (Ashford-Hanser, 2020).

Oftentimes these students are motivated by passion for the discipline, a sense of responsibility to serve marginalized peoples, and a means of attaining autonomy (McGee et al., 2016). In other cases, they are inspired by mentors, undergraduate research opportunities,

supportive family, and prior work experience (McGee et al., 2016). Fueled by these motivations, these students could be retained with the fostering of a sense of belonging, a salient disciplinary identity, and supportive institutional factors, thus countering the attrition trends so often reported in STEM graduate education (Curry and DeBoer, 2020; Murray-Thomas, 2018).

This study asserts that a sense of belonging plays the primary role in the attrition equation (Master et al., 2016; Mooney and Becker, 2020; Mooney et al., 2020). Building on prior research, we designed this inquiry to further explore the complex nature of identity (social and disciplinary) and sense of belonging in the context of a community (computing research group; Mooney and Becker 2020; Mooney et al., 2020;). This study was designed to expand our understanding of the pathways and experiences of Black women in a computer science doctoral program and expand the current knowledge on the ways that community, sense of belonging, and identity affect persistence in computer science doctoral programs.

3. Theoretical Frameworks

This study leveraged three frameworks—*intersectionality*, *social identity theory*, and *landscapes of practice*. We used intersectionality as a conceptual framework as the foundation for the intentional exploration of Black women in computer science and as an analytical lens to understand our participants' positioning in their landscape of practice. Social identity theory was the guiding framework, and landscapes of practice served as an interpretive or analytical framework. In the following section, we define all three frameworks, describe why they are appropriate, and explain their relevance to the study.

3.1 Intersectionality

Intersectionality is a theoretical framework that attends to the complex and often convoluted experience of being situated at the intersection of various identities, including race

and gender (Crenshaw, 1989). The framework has its roots in critical race theory, which draws attention to the power and structures that exist and often perpetuate actual and perceived feelings of oppression or inequity (Delgado and Stefancic, 2017). The theory was established in legal scholarship but has been extended to work in sociology, education, and even computer science education (Ross et al., 2020). Oftentimes, Black women grapple with explaining, describing, and making meaning of their gendered and racialized existence within structures that were not designed for them; as referenced earlier, being a woman in computer science is different from being Black in computer science, and both are different from being a Black woman in computer science. Fortunately, new work is beginning to provide the foundation for exploring intersectionality in computing to better understand those who are situated at the intersections of race, gender, and technology (Ross et al., 2020). This conceptual framework is appropriate for two reasons: (1) it establishes the premise to look explicitly at Black women and their experiences in the case; and (2) it is used as an analytical lens for understanding the power relations that exist in their landscape of practice (Collins and Bilge, 2016; Pyrko et al., 2019). Scholars have argued that intersectionality can be used to interpret and/or explain how people relate to one another, including who is advantaged or disadvantaged within social interactions in a community (Collins and Bilge, 2016). As such, intersectionality provided a theoretical guidepost for developing interview questions that elicited participants' perceptions of their racialized and gendered experiences, how they made meaning of those experiences, and how social interactions in their landscapes of practice influenced their identity in computing. Likewise, the theory was used to interpret the more complex experiences associated with determining and/or understanding how the participants talked about themselves in relation to race, gender, and their computer science identity.

3.2 Social Identity Theory

Social identity theory is a framework that many scholars use to understand one's ascribed racial, ethnic, or gender identity (Tajfel, 1981). Some scholars use identity to refer to a social category (e.g., a social movement, creating a common culture among participants), while others use identity to refer to the parts or roles of a self, constructed by meanings that a person attaches to the many roles they play in their world or role identity (e.g., science identity, engineering identity, etc.; Stryker and Burke, 2000). There is also debate about the means by which these identities are constructed and ascribed. One body of scholars believes that identity is constructed and ascribed by external social structures. These structures and systems define or influence an individual's self-concept and behaviors. The other body of scholars places the identity formation and adoption on the "internal dynamics of self-processes and behaviors" (Stryker and Burke, 2000, p. 285). The first group focuses on the influence of social structures on identity development, while the latter focuses on how individuals internalize and enact identity. To add further complexity, there is a third body of literature led by McCall and Simmons (1966) that asserts that the two directions are intricately intertwined in a two-way communication, each constantly either confirming or disproving the other. The social structures inform internal process, which projects the (external) behaviors back out to the social structure through a person's behavior (McCall and Simmons, 1966). For this work, we rely on the operationalization of McCall and Simmons (1966) that identity is an ongoing negotiation between self and external structures. In this manner, social identity theory provides the lens for understanding the construction, ascription, and malleable nature of identity. This interplay of identity development also goes beyond our social identity understanding and extends to what scholars refer to as disciplinary identity (Godwin et al., 2013; Ross et al., 2017, 2021).

Disciplinary identity was derived from role identity and is composed of the roles we assume in the context of an academic community. These roles or identities are then often considered fluid or malleable, oftentimes as a result of context (Godwin et al., 2013). In some contexts, one's identity may be very salient (or strong), and in other contexts, it might be less salient (or in jeopardy). For example, at a conference for women engineers, a woman with a degree in engineering might confidently assume the identity of an engineer (salient identity); however, after returning to her firm, in an environment in which she is given a different role or undervalued, she may feel less like an engineer (not salient identity).

To measure or evaluate disciplinary identity, prior research in science education and engineering education has confirmed and validated a set of three subconstructs: interest, performance/competence, and recognition (Carlone, 2017; Choe et al., 2017; Godwin et al., 2013). Interest often measures how interested a person is in a discipline or explains the reason for interest. Performance/competence refers to how a person describes their performance or perceived competence. Recognition often refers to the recognition by others of a participant's engagement in a discipline or how well they perform (Carlone and Johnson, 2007). Prior quantitative and qualitative work has established disciplinary identity as being a predictor of engagement, persistence, and retention in several STEM fields, including computer science (Carlone, 2017; Choe et al., 2017; Godwin et al., 2013; Taheri et al., 2019). However, recent work in computer science education research has extended beyond those three subconstructs to include sense of belonging (Dou et al., 2019; Taheri et al., 2019). Sense of belonging refers to whether a person perceives inclusion in a community (Cheryan et al., 2009). Do they describe themselves as being part of the computer science community rather than feeling not welcome? When exploring computing identity, a structural equation model indicated that sense of

belonging had a direct effect on perceived competence and performance of undergraduate computing students, suggesting that the more students felt like they belonged, the higher their perception of their competence in the field. This extension of the computing identity framework to include the subconstruct of sense of belonging has created an opportunity to qualitatively explore the sense of belonging of Black women in computing in the context of identity formation and sustenance.

Social identity theory served as the guiding framework of our study, which was designed to understand the engagement and persistence of Black women in a computer science PhD program. The computer science disciplinary identity provided a lens for understanding why and/or how these women traversed computer science through to a PhD program. For this reason, social identity theory contributed to the development of the interview protocol. The prior work of Ross et al. (2021) served as the basis for questions that explored the subconstructs of identity, including interest, performance, and recognition; likewise, each participant was asked if she ascribed the identity of computer scientist to herself. Additional questions were added to probe sense of belonging in the research group and the broader computing community. Identity theory also served as an analytical framework, as the *a priori* codes developed in the first iteration of analysis were established using identity theory and its (further described in the Methods section).

3.3 *Landscapes of Practice*

The concept of landscapes of practice builds upon the work of Lave and Wenger (1991), who explored identity in practice through their work on situated learning theories and communities of practice. Communities of practice are defined as communities “created over time by the sustained pursuit of a shared enterprise” (Wenger, 1999, p. 45). One’s existence or placement into a community allows them to acquire the tacit knowledge associated with the

norms and values of that community (deChambeau, 2014; Pyrko et al., 2019; Rynearson, 2015). Through social interaction, individuals in a group have the benefit of situated learning—learning through active participation in the community (deChambeau, 2014; Rodriguez and Lehman, 2017). This situated learning eventually leads to the development of a disciplinary identity and a path to full membership: a newcomer enters the community as a novice and through legitimate peripheral participation, they take on small tasks, grow, learn, and move toward full membership as they acquire the vocabulary, norms, and values, and eventually master the tasks of the community. Entering a community of practice as a novice thus means dealing with the regime of competence to transform one’s identity (from legitimate peripheral participation to full membership) and reflect the accepted experience levels of the community. As Wenger-Trayner et al. (2015) pointed out, this conceptualization highlights the trajectory of an apprentice from periphery to the center of a community—oftentimes resulting in a salient disciplinary identity.

Communities of practice can be formal or informal in their organization and structure (deChambeau, 2014; Elfer et al., 2017; Rynearson, 2015; Tull et al., 2014). However, they all include a few key elements: relationships, shared practices, and learning (deChambeau, 2014; Elfer et al., 2017; Rynearson, 2015; Tull et al., 2014). Some examples of communities of practice include classrooms, research groups, student organizations, and professional organizations. An individual can participate in one or many of these communities simultaneously. Participating in many communities thus results in having to negotiate multiple identities.

This negotiation of many communities and multiple identities is the foundation of landscapes of practice. Landscapes of practice is an extension of communities of practice and is defined as a complex system of multiple neighboring communities that interact and compete for

their claims over knowledge and expertise (Wenger-Trayner et al., 2015). As people, we often reside in a landscape of practice. In some cases, we find ways to merge or at least find planes of overlap to move fluidly throughout the landscape; however, there are instances where people find it best to keep their communities separate and traverse between them, leaving the norms and expectations within the communities they have vacated to enter a new community. This participation in many communities is often referred to as *multi-membership*. How we navigate to and through this multitude of communities is often predicated on our perception of self within these communities, as well as the norms and expectations within these spaces. Oftentimes communities “promote or accommodate particular identities and not others [...] an individual may find that they do not fit in that place” (Wenger-Trayner et al., 2015, p. 65). This often creates a boundary that limits a participant to a role of *tourist* or *sojourner* in that space. A tourist is defined as a visitor who engages superficially in the local space, but whose identity remains unchanged or uninfluenced by their participation in the community. In contrast, sojourners are visitors who are more fully engaged in the community, but whose identities are changed or influenced in some way; however, they still recognize or perceive that their participation has not quite resulted in membership into the community (Wenger-Trayner et al., 2015, p. 44). They are there, they participate, they follow the rules, but they are not quite a member.

For this study, landscapes of practice provided an analytical lens that aided in the interpretation of the findings. Where social identity and communities of practice failed to explain the absence of identity salience amongst some of the participants, landscape of practice provided a lens of understanding. For the women in this study, their landscape of practice consisted of their research group, the broader computer science community, and the many racial/ethnic or gendered professional organizations they traversed.

Based on the foundation developed by scholars exploring intersectionality (Mwangi et al., 2019; Perkins et al., 2020; Ramirez, 2013), social identity theory (Choe et al., 2017; Daniels and Brooker, 2014; Kajfez and McNair, 2014; Perkins et al., 2017), and landscapes of practice (Wenger-Trayner et al., 2015), we used these frameworks to better understand the experiences of women of color in a computing PhD program. Through the following research questions, we explored how self-identification as a Black or Hispanic woman in the field of computing resulted in full participation and identity salience for some, but marginalized participation and less salient identity development for others.

4. Research Questions

The purpose of this study was to provide a deeper understanding of computer science identity and its role in relation to the persistence of Black women in computer science PhD programs by answering the following research questions:

- 1) How do Black women PhD students in computer science describe their computer science identity?
- 2) How do landscapes of practice influence computer science identity formation or salience of Black women in a computer science graduate program?

5. Methodology

For this work, we present a case study (see Fig. 1) in which the boundary is one computer science PhD program at a predominantly white institution (PWI), and the focus is the Black women enrolled in the program. Participating in this study were four women from one research group with explicitly defined support structures (described in section The Bubble), and one woman from a research group without these structures. In this section, we define the methodology, describe appropriateness to the study, and demonstrate how it was used in this

work. Likewise, we present the steps taken to ensure we protected our participants—a vulnerable population—as well as the processes invoked throughout the study to enhance the quality, accuracy, and truthfulness of this inquiry.

5.1 Case Study

When designing this work, we used a case study approach. Leveraging the definition of case

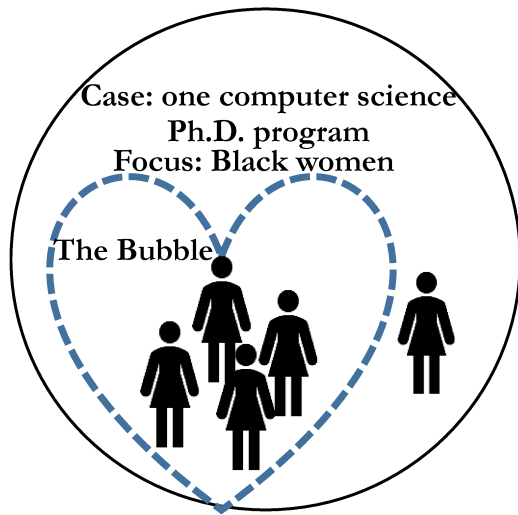


Figure 1 Research Design

study by Stake (1995), our objective was to study a bounded system to better understand the complexity within that system (Johnson & Christensen, 2019). Within this definition, the system is “a set of interrelated elements that form an organized whole” (Johnson and Christensen, 2019, p. 395). *Bounded* implies that there is a boundary to the system or the case, and, in adherence with traditional case study methods, there is also a focus (Miles and Huberman, 1994). Case studies are often used to learn about “little-known phenomenon” to describe in depth the experiences of the focus population of the case (Johnson and Christensen, 2019, p. 396; see also Miles and Huberman, 1994). As such, we define our case as one computer science PhD program with a particular focus on the Black women in the program. Given the focus on the women, their experiences, and their mechanisms for meaning-making in computer science, we executed the interpretive orientation, meaning that we gave deliberate attention to the lived experiences (of the participants) in the case, as well as their connection to larger structures (the broader computer science community; Denzin and Lincoln, 2018). Because case studies often incorporate more than one form of data, we collected and analyzed the following data: in-depth interview data with four women from one research

group, which we will refer to as *the bubble*; in-depth interview data with one woman not from the research group; and documentation that reflected the guiding principles used in establishing the bubble (or research group) in the case. The documentation was mainly used to contextualize the experiences of four of the five participants.

5.1.1 The Case

The case is a computer science doctoral program at a PWI, bounded by the computer science doctoral program and focused on five Black women enrolled and matriculating in the program. The objective of the study was to better understand the experiences of Black women in a computer science doctoral program as it relates to persistence in this field. We spoke to four women who were in the bubble and one woman outside of the bubble. The woman external to the bubble qualified as being part of the case because she was a Black woman computer science doctoral student at the selected institution. In the interest of protecting the identities of the participants, we will not give any additional details about the case.

5.1.2 The Bubble

Within the case itself, we found what one participant called “the bubble.” The bubble is a particular computer science research group within the case. Within this study, we wanted to understand the supports provided within the bubble, and how these women perceived those supports in terms of helping or hindering their identity development, salience, and sense of belonging. In addition, we wanted to understand how this bubble fit within the landscape of practice that they participated in. We also wanted to know how the experiences of the women in the bubble differed from those outside. The group was led by an advisor whom we will refer to as Maya. Maya established her research group using six principles: (1) recruit strategically, (2) establish community, (3) foster a research culture, (4) provide holistic advising, (5) provide

funding, and (6) promote professional development. To recruit for the program according to these principles, Maya visited computer science programs at Historically Black Colleges and Universities (HBCUs) and recruited pairs of students for the research lab. The deliberate attention to recruiting pairs helped in establishing the community mentioned in Principle 2. In addition, Maya encouraged all students to share resources and experiences, and to participate in peer mentorship to create a supportive, transparent community within the lab. All the students either self-selected a research project to contribute to, or were assigned work upon joining the research team, to help them gain the discourse, norms, and values of the research community. Maya funded all these students and encouraged them to participate in traditional academic professional development such as conferences and colloquia.

Through this strategic endeavor, she established a computer science research group with more than 15 women who self-identified as either Black, African American, or Hispanic. In reflecting on the demographics in computer science, this was unprecedented. For these reasons, this research group was of particular interest for an inquiry that would provide insight into how these women came to pursue computing as an occupation, how they describe their experiences in this environment, and how those experiences relate to how they see themselves in computing.

5.1.3. Participant Sampling

The study consisted of interviews with five Black women enrolled in a computer science PhD at one university. Four of the participants were part of the bubble, and one was not (see Table 1). Avatar, the participant not in the bubble, was a Black woman in computer science at the same university, and thus is considered part of the case, ultimately presenting another perspective from within the case. Participants were recruited through snowball sampling (Creswell, 2013). The recruitment began with one participant in the case who subsequently referred a friend, and so on. Through this snowball sampling, Avatar was interviewed, and while she was not part of the research group, her pathway to computer science was similar and she was part of the case. Because her experience in computer science provided insight and contributed to our interpretation of the findings, we included her as a complementary perspective in the case.

Table 1. Participant Descriptions

Name	Race/Ethnicity	Yr	<i>Bubble</i>
LaTanya	African American/Black	2 nd	Y
Cicely	African American	4 th	Y
Alexis	African American	5 th	Y
Janine	Black	7 th	Y
Avatar	Black	3 rd	N

All the participants had attended a minority-serving institution (e.g., HBCU or Hispanic-Serving Institution [HSI]) for their undergraduate degree. During the interview phase of this study, all the participants were enrolled in a computer science PhD program; however, their undergraduate majors included computer engineering, computer science, math, and information technology. Except for the one, they were all recruited into the same research group, though they were studying different research topics. The participants' years of study ranged from second year to seventh year in their graduate programs.

5.2 Data Collection

In accordance with case study methodology, we collected two types of data: mentor model artifacts, also referred to as artifacts, and five interviews. The data collection process and handling are described below.

5.2.1 Artifacts

One data point for this research study was a set of published mentoring guidelines that served as the model for the research group. The mentoring plan consisted of six principles for effectively mentoring Black/African American computer science doctoral students. The research team collected written and digital artifacts associated with this effort to understand the context of the research group and to shape the interview protocol for information related to the execution of

the mentoring plan. The data was publicly available through the web, and a paper copy of the guidelines was also acquired from the research group advisor (Maya).

Given the scarcity of graduate research groups with racial and ethnic diversity in computer science, we took extra precautions to protect vulnerable populations in masking the participants' identities from being discovered. Since we already risked the potential to identify the participants through deductive disclosure by describing the case, we did not want to further increase our chances of breaching confidentiality by revealing specifics related to Maya (Kaiser, 2009). Therefore, we decided not to interview Maya, but instead rely on publicly available information via the artifacts.

5.2.2 Data Collection: In-Depth Interviews

In order to understand the pathways and experiences of the participants, we elected to leverage interviewing as the method of data collection (Seidman, 2013). Given the scope of the research questions, we determined that the flexibility of a semi-structured in-depth interview protocol would elicit the richest data. While the protocol was driven by the theoretical framework of social identity theory, it was also designed to allow the participants to elaborate when necessary. This flexibility allowed the participants to tell their stories about acquiring knowledge of computer science, and about traversing the space from undergraduate to graduate school. The protocol also included questions related to the mentoring model (derived from the mentoring artifacts) to illuminate adherence to the model itself.

The interview protocol was designed to elicit not just a beginning, a middle, and an end to the participants' stories, but also to provide their lived experiences, including how they made meaning of their presence in computer science. The interview protocol included questions that explored their backgrounds, social engagement, meaning-making processes, and career

aspirations (full interview protocol available in Appendix A). For sample interview questions, see Fig. 2.

1. What is a computer scientist?
2. Do you see yourself as a computer scientist?
3. Do you feel others see you as a computer scientist?
4. Are you involved on campus? In what ways?
5. Are you involved in professional organizations on campus (e.g., WICS, ACM, IEEE, NSBE, SHPE, SWE, etc.)? Why or why not?
6. Describe your peer relationships in computer science?
7. Do you feel like you have been a successful computer science major?
8. How do you define success?
9. Now that you have talked about how you came to computer science, what it is like to be in this major, department, and/or on this campus?
10. How do you feel your identity as a Black woman has shaped your experience?

FIG. 2: Sample Interview Questions

The questions were designed to capture the participants' perception of the communities of practice they were engaging with or participating in, and their perceptions of membership in these communities. The questions were also designed to elicit the context in which their disciplinary identity was constructed, and how that identity was either affirmed or challenged in the context of the computing community (disciplinary identity salience). The interview protocol was International Review Board approved, and all the interviews were audio recorded, professionally transcribed, and redacted for anonymity.

5.3 Data Analysis

The analysis was conducted by three researchers leveraging thematic analysis. Thematic analysis is a qualitative research method used to identify patterned meaning across a data set (Clarke and Braun, 2018). We used the two types of data (mentoring artifacts and interviews) and the methods described in detail below to establish a better understanding of the construction of the bubble for context (community of practice), and the impact of the bubble on identity

development salience of our participants. The team used this approach to converge on central organizing concepts that would aid in the construction of themes that described how programmatic support structures impacted the participants' computer science identity.

Analysis began with the primary author reading through the transcript of each participant with no coding at all; this resulted in the development of *contact summary sheets* for each participant (Miles and Huberman, 1994). A contact summary sheet is a single sheet with an overall summary of the interview that highlights some of the themes, concepts, and issues. Our contact summary sheets also captured the demographics of the participant and transition points in her journey to the computer science doctorate. After we developed the contact summary sheets, we selected and read the same participant interview (meaning each researcher read the same transcripts). After the cursory read for context, each researcher analyzed the transcripts using *a priori* codes based on the proposed operationalization of identity (Saldaña, 2021). *A priori* codes are codes that are driven by the theoretical framing of the research and are thus predetermined, in this case by social identity theory. This required the team to analyze the data looking for elements of interest, recognition, performance/competence, sense of belonging, and disciplinary identity. After the theory-driven coding, the research team transitioned to an emergent coding schema; these *in vivo* codes, which emerged directly from the participants' language, were used to better understand the incongruence between how the participants described their journey to and through computer science, and how they self-identified when asked if they were a computer scientist (Saldaña, 2021). This *in vivo* coding resulted in our central organizing concepts: (1) reconstructing the moments that seemed impactful in shaping their computer science identity, (2) showing how they passed through borders in their landscapes of practice, and (3) exploring their perceptions of residence in the computer science landscape. Once the researchers converged on

these concepts, a third iteration of coding was executed using structured coding as the mechanism for identifying moments of impact, boundary spanning, and residency (or lack thereof) in both the communities and the landscapes of practice (Saldaña, 2021). We completed this process for all five interviews.

5.3.1 Privacy and Protection of Participants

We know from prior literature that Black and Hispanic women are grossly underrepresented in computing (Zweben and Bizot, 2020a). Furthermore, the concentration of many Black and Hispanic women in one computer science research group is even rarer. Therefore, we had to take tremendous care and consideration in the handling of the data, the interpretation, and now the reporting of the findings (Gubrium et al., 2012). As stated earlier, we were concerned about deductive disclosure; therefore, we did not report on the year in which the data was collected, we avoided interviewing Maya, and we asked all the participants to self-select a pseudonym to be used in the reporting (Kaiser, 2009). Even though we have taken steps to ensure that personal identifiers were removed from the data, the contextual identifiers remain. As a mitigation strategy, we were careful to select quotes that were sufficient in supporting our claims while avoiding quotes with unique details that could reveal their identity (Kaiser, 2009). We avoided modifying the words of the participants to avoid potentially compromising the integrity and quality of the study.

5.3.2 Quality

We elected to follow the four principles for assessing quality introduced by Yardley (2000) as the framework for achieving quality in our study. Yardley (2000) identified *sensitivity to context, commitment and rigor, transparency and coherence, and impact and importance*. Sensitivity to context is giving attention to the sociocultural setting and participants'

perspectives. Our election of frameworks that tend to the power associated with race, gender, and community culture aided in developing this sensitivity to sociocultural contexts. Commitment and rigor refers to in-depth engagement with the topic, methodological competence or skill, thorough data collection, and analysis that illustrates both depth and breadth. This was achieved through the adoption of the semi-structured interview. The semi-structured protocol provided the structure to explore a breadth of topics but also the opportunity for participants to elaborate as much as they were comfortable with, providing depth. Likewise, the team committed to a systematic execution of the analysis to ensure we were consistent in our interpretation of the findings. Transparency and coherence includes the clarity of description or argument, transparent methods and data presentation, theoretical and methodological compatibility, and reflexivity. The inclusion of our statement of positionality (see Section 5.3.4, Positionality) for transparency and commitment to alignment between research questions, theoretical framing, methods, and reporting for coherence were our deliberate attempt to increase the quality of our study. Impact and importance refers to the theoretical understanding, sociocultural understanding, and practical application or implications of the study. We provide evidence of our adherence to these four principles in the Theoretical Framework and Methodology sections through transparency and intentionality.

5.3.3 Positionality

The inquiry presented in this manuscript was conducted by three primary researchers and two additional authors. The first author designed the research study and was involved in the execution of the research from data collection to dissemination. The second and third authors were instrumental in the data analysis and dissemination of the work, and the fourth and fifth

authors aided in the external validation of the findings to ensure the research team was authentic in our co-construction of the meanings of the participants. We have provided positionality statements from the data collection and analytical researchers for the project.

The first author is a Black woman engineer who studied computing in both undergraduate and graduate schools. She acknowledged that previous experiences in all the domains may influence the interpretation of the findings. The first author conducted the interviews and engaged in the data analysis with mindfulness and deliberate attention to intentional practices of reflection. The second author is a Middle Eastern woman trained in material science and engineering. She has worked as a K-12 science teacher and pursued a PhD degree in STEM education. As her research interests center on diversity, equity, and becoming in STEM fields, she paid special attention to hearing the voices and honoring the experiences of the participants and understanding the context of their journeys. The third author is an Indo-Canadian PhD student pursuing her degree in computer science. She recognized that her background and experiences in computer science could influence her interpretation of the findings and as such remained cognizant of this potential bias when engaging with the interview transcripts.

6. Findings

Throughout the interviews with participants, three major themes became apparent: *moments of impact*, *boundary spanning*, and *communities of residence*. In this section, we define each theme and provide evidence to substantiate these claims.

6.1 Moments of Impact

Moments of impact are defined as the experiences and/or people who influenced the participants' choices to pursue computing as an occupation. These moments of impact could occur prior to undergraduate education, or any time along the trajectory to and through the

computer science doctorate. They were noted as being the moments that contributed to the participants' decision to pursue computer science as an occupation, and in some cases, that shaped their computer science identity. This identity was defined previously as including their perceived interest, performance/competence, recognition, and sense of belonging in computer science. The participants in the study described the influence of a family member (interest), the encouragement of a professor early in their academic pursuit (performance/competence and recognition), and the realization that they could merge computing with other passions (interest).

A common influence on occupational pursuits among the participants was family. In some cases, it was the factor that kept them from engaging with computing; in other cases it was the factor that provided motivation to persist when faced with obstacles. LaTanya, for instance, initially had an unfavorable impression of what it meant to work with computers derived from how she perceived her father's work life:

When I was little, he worked with computers. What he did, I don't know. [...] I was like 'cool,' he works for a really long time, and he comes home angry. I don't want to...this is not something...computers aren't fun. (LaTanya)

This exposure, with LaTanya's limited understanding about what her father did and keen attention to how it made him feel, made her discount computing as a career aspiration until college (disinterest). Meanwhile, Alexis was encouraged by her family to pursue engineering due to her performance in science and mathematics (performance/competence and recognition).

Another common moment of impact for the participants was computing role models. Most of the participants described the one Black woman instructor they had in their introductory programming course as being the reason they enrolled in computer science as a major, why they switched majors to computer science, or why they persisted through to a PhD. These models

either encouraged them, challenged them, or recognized them in a way that had a lasting impact and served as the foundation for their computer science identity development and helped them remain engaged.

Alexis was not introduced to computer science until her first year in college when she attended her first course in coding, in which she was very successful. The Black female professor of this course suggested that Alexis switch to a computer science program. This professor had a profound impact on Alexis's success in computing, but she also piqued her interest in graduate school: since the professor was not a PhD, Alexis was inspired by the absence of a "Black doctor woman" at her HBCU; she wanted to become a doctor to show Black children, like her, that "hey, you can be a Black PhD, too."

Janine described her first programming professor (a Black woman) as the person who challenged her to take on more difficult tasks and to work as a "lab helper" for other students. While Janine had no initial intention of attending graduate school, after some encouragement from that professor, some familial pressure, and a personal invitation from Maya, Janine was set to obtain a PhD in computing. Being recognized as a scholar in the field and her family, and as someone who could succeed in the field of computing, helped her to see herself in a computing graduate program.

LaTanya also discussed the impact of her first introductory programming course where she was exposed to the larger scope of technology by an African American woman who worked at Google. This interaction played a strong role in changing LaTanya's perception of computer science: "Wow, not only do you have this amazingly great job apparently, because you're working at Google, but you like what you do, and you're happy, you can smile, and you like teaching us" (LaTanya). The presence of someone who looked like her, was happy in the

discipline, and shared her knowledge with her provided an opportunity for LaTanya to relate to being a part of the computing field.

The final noted moment of impact was the realization that computer science provided an opportunity to merge additional passions with technology. The idea that they could expand their expertise in computer science into disciplines that brought them fulfillment outside of the traditional computing sub-disciplines (for example, the convergence of altruism with technology), was not only appealing, but perhaps also a contributor to increased interest and engagement. Alexis decided to merge the influence of her mother and sister (both teachers) with her passion for computer science to pursue her PhD in computer science. Likewise, Cicely merged her two passions for computers and youth as a research area for her PhD pursuits.

6.2 Boundary Spanning

When defining landscapes of practice, we described a landscape as being the collection of communities of practice that an individual engaged with or actively participated in. In this manner, we positioned landscapes of practice as a means of understanding computer science identity salience. When talking to participants about their experiences in a computer science PhD, they were mixed on ascribing a computer science identity self. Even though they had sought to integrate themselves into the computing community through participation in computer science community of practice, some never felt as if they had achieved membership. This absence of membership and sense of belonging pushed them to traverse many communities, leading to boundary spanning. Boundary spanning is a term used to describe the ability to traverse across the boundaries of many social spaces (Jesiek et al., 2018). In some cases, these organizations or communities of practice fulfilled a need to be around women, ethnic/racial minorities, or computing colleagues. When participants described their landscape, they often

described communities that affirmed their computer science identity, gendered identity, racial or ethnic identity, or graduate student identity, and in most cases, some intersection of these identities.

As a means of navigating graduate school, many of the participants amassed membership, sojourner, or tourist status in many student and professional organizations to augment the existing graduate support systems. They often described participation in professional organizations, for example the Association of Computing Machines (ACM); racial or ethnic professional organizations, for example the National Society of Black Engineers (NSBE) or the Society of Hispanic Professional Engineers; and gendered professional organizations such as the Society of Women Engineers. They also identified their research group as a community that assisted them in their social and professional growth and development.

In most cases, the participants of the study described the boundaries between the different social spheres as permeable, and as such, they were able to move in and out of the spaces; however, they did not always feel as if they belonged in all these spaces. The three spaces most prevalent in their discussions were the *Black graduate student organization*, their *research group*, and the broader *computing community*.

Most of the participants talked about seeking out the Black graduate student organization upon arrival to their campus. Early in their graduate journeys, they recognized that being Black in graduate school could be isolating; therefore, they sought out mentorship and community among other Black graduate students.

[PWI], did not want to be there at all. Was ready to come home after the first month. It was a culture shock mainly from [HBCU] to [PWI] with all these kids. I was like, 'I'm going to get lost.' At the time, and I can tell my lab mates now, because we're friends, but

at the time, the lab was very cliquey, so everyone had their own thing, and I was like Because I basically came in by myself into the lab. One of our other student's friends, she was transitioning from [field] PhD, so everyone knew her, but I was brand new. I was like, 'Maybe this ain't for me.' I wasn't feeling welcome, but I did click up with the Black grad student association, so they kept me sane during my first year. (Alexis)

The Black graduate student organization thereby served as a transitional space for Alexis between joining the university and feeling welcomed into her research group. However, once participants settled into the research group via research project assignment, peer mentoring, and relationship building, they believed that they were insulated from the traditional chilly climate so commonly accepted as the norm in computing, especially towards women and people of color. As one participant described “We won’t have some of the same problems that a lot of other people will have. We’ll never be able to say ‘I was isolated in grad school.’ That cannot happen in our lab” (Janine).

The research group environment had established a culture that made the transition from an HBCU to a PWI less abrasive and startling. This was in part due to the racial/ethnic and gendered composition of the group, and in part due to the mentorship structures established in the group.

I feel very fortunate to be in the lab where I have so many people that are like me—gender and race. [...] I don't know if I would be in this field if I didn't have the support. [...] I don't know if I would just have persisted or not. (Cicely)

Participants described an environment that was family-like, including comparisons to siblings who reached out and checked in on one another if someone appeared to be less engaged. They were encouraged to take classes together to combat feelings of isolation and to provide academic

and moral support to one another. More than one participant credited her persistence in the computer science PhD to the support in the research group “Then, even in class, we always take classes in pairs. You’re really never in a class by yourself. [...] Even if someone is super quiet, somebody’s going to say, ‘have you heard from such and such, oh call them’” (Janine).

The women also talked about the structure of the research group and its influence on their social integration, development as scholars in their field, or their professional development. Each student was recruited personally by the mentor/advisor of the research group,

And so, I ended up applying, and I emailed her, told her that I applied to [institution], and she ended up calling me [...] we had a great conversation and I got accepted [...]. They flew me [out] for the Spring visit and whatnot. I just felt comfortable with my lab. It was just essentially perfect, for me. [...] I could of had that opportunity to go to an Ivy League coming from undergrad, because I did really well in high school, I graduated with a 4.0. I just didn't want to do it. [...] And so I know how important a community is to me and I felt like I wouldn't have one at [Ivy League] but coming to [the bubble], even during my visit, I felt welcomed. I felt like the administrators liked me, I felt like the other students in the lab I would be in were comfortable. It didn't seem like anything would hinder me along my way. I felt like I would have that helping hand when needed. And so, it was just an easy decision. (LaTanya).

A phone call from the advisor inviting each student to join the group established the environment for the students and established an expectation of familial engagement:

Well, the lab [...] we talk a lot, probably daily. We go to each other's houses and eat and things like that. We go out to the movies. But I think my role (kind of) in the lab... I'm more the mentor. I'm one of the senior students, so I'm kind of the...I don't want to say

I'm the mother hen, because it's not that...but it's more of...I'm the big sister kind of thing. (Janine)

Such relationships helped the participants develop socially within the group. Likewise, students were encouraged to follow the *footsteps* of those ahead of them.

It's a three-year gap after me between the next incoming student, but luckily there wasn't a three-year gap before me, because Janine, I don't know if you're going to meet her, but Janine, she's going to be finishing in [soon], so [...] just seeing first-hand and being able to help with her, or just basically following behind her, like when she did her proposal, I made sure I read it, made sure mine looked like hers. "Send this to Janine, send this to Janine." [...] because Janine's also ahead of me, I'm basically riding their coattails [...]. 'Let me see what you're doing, hold my hand,' and then I'm trying to do the same thing for the people who came in three years behind me. So, making sure that we have the different cohorts with inside the lab has helped a lot. (Alexis)

This peer-led model, coupled with familiarity associated with the gender and racial composition of the group, allowed the students to focus on their studies. In addition, students were encouraged to participate in the activities that were valued by the academy to develop them professionally beyond the boundaries of graduate school through professional organization participation: ("There's certain organizations that Maya wants us to join. I join them because I'm a member of ACM [Association for Computing Machinery], I am a member of IEEE [Institute of Electrical and Electronics Engineers]" [Janine]), grant writing, and conference participation ("No, I have a good number.... How many first author? Like four. But I know some people have 20-something publications. One of my lab mates, he had a lot. He would just publish, publish, publish" [Janine]).

The participants also talked about the necessity and challenges of creating relevance in the broader computing community. While the research group provided a space to be Black, to be a woman, and to be a computer scientist, the participants still longed for acceptance beyond the boundaries of their research group: “They brought me to a place out of my comfort zone, while still being in it at the same time” (LaTanya). The participants thus sought this feeling of belonging through their participation in traditional computer science professional organizations like the ACM, Upsilon Pi Epsilon, and programming competitions. However, they also described a divide between their research group and those other communities:

But there was definitely a divide. So, between people who did computer science and people who did [our research], it just so happened that all of the people who did [our research], looked like you and me [Black women]. (Janine)

This perceived divide made accomplishments like publishing at respected conferences and top-tier journals seem unattainable, and for those who noted success at both milestones, they still saw their work as not being respected and not being a big enough contribution to the larger community. This uncertainty associated with their competence in the broader field left most of the participants in the periphery of participation, in the margins, and relegated to sojourner or visitor status, preventing some from claiming a computer science identity.

On the other hand, Avatar desired membership in other communities outside of her research group, but she found that the demands of her lab took too much time. She found instead that she was primarily a fiscal member (paying dues) of the organizations (e.g., IEEE, ACM, Cyber Club, NSBE), but not actively participating in meetings and events. She even noted her desire to find community in the bubble (Maya’s) research group, but her physical proximity kept her in the periphery of even the intersectional community.

I'm in the group chats, I'm in the site chats. I'm in everything. We hang out or whatever but it's just when you're not there you miss the day-to-day stuff. [...] it's like you miss out on, 'Oh, who wants to go get Chili's after?' You miss out on that. Then, you see the pictures and you're like, ugh. [...] everybody pretty much knows I'm not available. I'm pretty much never available anymore. But when I first came here that was one of the reasons why I was really excited because I had that oasis but, I realized that I could not depend on that oasis. It's like a crutch I had to kind of...I had to be comfortable in my own skin and in my lab. I couldn't just be comfortable there and just come here and think that was going to work because I was just going to always like, 'ugh, they this, this, and that.' Then, go back here and deal with it. That wasn't healthy. So, I had to get comfortable. (Avatar)

Avatar thereby found permeating the boundary of her research group difficult, leaving her mostly in isolation. She did not feel comfortable ascribing a computer science identity to herself nor did she feel as if she belonged. Even though the bubble created an oasis, she still did not quite feel like she had a place there as well, largely due to the demands of her research and her lack of availability. This left her trying to find ways to feel comfortable within her research group and move from tourist to practitioner.

6.3 Community Residence

Community of residence is defined as the space in their landscape where the participants perceived they were no longer participating in the periphery; in other words, these were the spaces where they had achieved full membership. As such, we sought to determine whether the participants ascribed a computer science identity to themselves. Based on the literature and interpretation of the theory, if they did not consider themselves a computer scientist, and if they

described themselves as not belonging or being comfortable within the computing community, then they had not achieved residency in that community. Because the theory suggests that how we navigate to and through a multitude of communities is often predicated on our perception of self in these communities, a perception that we are not part of a community will often relegate a person to tourist status rather than resident. This interplay between identity salience and participation in many communities (in their landscape) had, in some cases, a harmful effect on identity salience, and in other cases, an increased computer science identity salience.

For example, despite Alexis's success in computing and her engagement in computing research since her sophomore year of college, she seemed to believe that she was disconnected from the broader community of computer science. She perceived this to be in large part due to the bubble created within her research group:

So, we're very lucky and like unicorns, because [Maya] who she is, and because she's [an administrator], like when I talk to other people in different departments, it's not the same, and I understand that it's not the same, so I feel bad, like I can't really relate. You guys got all these issues, we have our own little Black bubble in the middle of the [xth] floor with our Black advisors and the [administrator who's Black]. Like we don't...I really do think all things happen for a reason, and [the other PWI I applied to], I would not be as favorable, I feel. So yeah, very blessed and special that I was put with [Maya].
(Alexis)

Alexis reluctantly ascribed the identity of computer scientist to herself when asked; however, she believed strongly that her experience was different from majority student research groups, and thus believed this kept her from legitimate residence in computer science more broadly. She also

articulated that she did not believe computer science was an identity, but rather a way of thinking:

I used to just say it's a programmer, but even in our lab, we don't have to all have computer science backgrounds, so more so a way of thinking. [...] my way of thinking changed because of computer science, so I guess it's a certain way of thinking about how to solve problems, and then using the computer to solve those problems. (Alexis)

Alexis, through her narrative, described her pathway to computer science and included language that was consistent with the subconstructs of computer science identity (interest, competence/performance, and recognition), but was reluctant to claim a computer science identity or residence in the computing community. She deferred the question on identity toward a definition of computational thinking, and while she credited her residence in this intersectional community of practice for her success in computing, she acknowledged that this unique space may have isolated her from the broader computing community, thus leaving her with sojourner status in computing.

When asked how she introduced herself to others, LaTanya said she was “a grad student studying computer science.” Her language seems to indicate that she felt as though she belonged and was safe in the space she shared with her graduate peers on campus, but that her sense of belonging within the larger computer science community was not solidified to the same degree.

I was still shaky on the computer science environment and like the type of people that I saw in computer science. They seemed very closed off. And maybe I'm not a cultural fit for this group. Maybe I just like computers and that should be like a side hobby or an addition to something I do with a mathematical twist or what have you. (LaTanya)

LaTanya's definition of what it meant to be a computer scientist revolved around the idea that a computer scientist is anyone who uses technology to acquire a solution, despite their gender and ethnicity:

I'm trying not to have the world ruin this definition. It is a person with a passion that's willing to utilize technology to acquire that solution [...] So it doesn't matter if you have a degree, it doesn't matter your gender, your ethnicity, do you like playing with technology? Do you want to use it? You're a computer scientist. (LaTanya)

However, when asked if she, herself, felt like a computer scientist LaTanya replied, "No."

No. I'm trying not to have the world ruin me but they kind of ruin me every once in a while. When I think about it, no, I should be, I'm a grad student doing this. But no. [...] I mean I say computer science [when asked what I am studying] so they think I would be a computer scientist, but I don't think I'm a computer scientist. (LaTanya)

LaTanya questioned her identity as a computer scientist due to not feeling a sense of belonging in the computer science community, not because she was questioning her ability:

There are some individuals that look at some African American or just insert whatever ethnic minority woman, into a situation, it's like 'oh, she's only getting this because she a double minority' [...]. And so that brings up a whole slew of imposter syndrome [...]. I haven't faced anything academically that made me want to stop. (LaTanya)

When she initially began grad school, she wanted to be a professor and "inspire other Black babies to do the same thing" (LaTanya). She hoped to show others that looked like her and shared a passion for technology that they need not feel like a minority.

LaTanya's pathway to and through computer science was predicated on her perception of belonging within her graduate program/environment, and even though she had legitimate

participation (publications) in computing, she still assumed the sojourner role in the broader computer science community. She articulated that she felt like she belonged in the intersectional community of practice, but was not able to merge that community of practice with the broader computing community.

This case study indicates that despite success (matriculating in computing, working in computing, winning prestigious fellowships, publications, etc.) and being involved in several professional organizations, most of the bubble participants did not consider themselves a resident of the computing community. This discovery led us to wonder, if a computing identity salience had not been established in most of these women, why and how did they continue to persist?

Avatar, our participant who was not part of the bubble, provided a different experience, but one that affirms the importance of a sense of belonging. Avatar's undergraduate research experience solidified her desire to pursue graduate studies in computer science, and she started her graduate journey at an HBCU with the understanding that the current master's program would evolve into a PhD program. However, her less-than-favorable experience in graduate school began to challenge her identity as a computer scientist and researcher. She felt underprepared for her program and verbally abused by her faculty sponsor. As a result, Avatar applied for a PhD program elsewhere and was accepted. This was when she transitioned to a PWI and into a new research group. Avatar immediately found herself leading a research project her first semester in the PhD program. She not only began to feel overwhelmed by the responsibility, but her performance in her computer science courses, for the first time in her career, was poor and thus threatened her identity as a computer scientist.

So, first year was rough. [...] I'm the only Black female that's computer science PhD.

That's hard. [...] Nobody really got it, because it was like everybody was busting out

these 4.0s and I was like two point...I had never seen that GPA before. That was like gas prices. I was like, 'What is this?' I mean I was a 4.0 student for all of high school.

(Avatar)

At the onset, lack of support and communication with her advisor led to self-doubt and diminished her confidence in her ability, her sense of belonging, and her computer science identity. But, there was a turning point when her grades began to rebound, as she began to open a dialogue with her advisor about what it was like to be the only Black woman in her research group. She found that she needed to speak up for herself, and this improved her relationship with her advisor and her colleagues: "I've learned to speak up and I've learned to be Black. I've learned to be okay with being Black in computer science" (Avatar). Likewise, her research advisor began to encourage her to pursue research endeavors that aligned with her interests, beliefs, and passions: "He's like 'I want you to find the projects that fit you...whatever you're interested in'" (Avatar). As such, she began to create projects that embodied the research group foci and her interests. These interest-centered projects, along with community development in her research group (including the recruitment of another Black woman computer scientist to the group), presentations at conferences, and engagement in professional computing societies increased her computer science identity. This identity salience is, however, still challenged by her perceptions of others in her research group surrounding the rigor associated with her research area.

It's difficult because the project that we worked on is...the space is not, it's privacy and it's policy and things like that. It's technical but it's also privacy and policy related [...]. Just condescending. It's just like...even amongst your supposed cohort or peer, you still feel like your work doesn't matter or it's not as hard or rigorous. (Avatar)

When it came to Avatar's perception of self in the computing community, it was predicated on her perception of her research not being "computer-science enough." This perception of an extension of herself (her research) as not being computer science kept her from claiming residence within the computer science community. When posed with the questions "What is computer science?" and "Have you always felt that you were a computer scientist?" her sojourner participation is even clearer. Avatar described her residence in the computer science community as being context dependent. When asked "What is a computer scientist?" she responded with "I don't know. I don't even know and I'm a computer scientist" (Avatar). However, when asked if she felt like she was a computer scientist, she said,

I struggle with that because yeah, I think my community, like when I go to Maya's lab, I feel like I'm embraced as a computer scientist, of course if I go home with my family or whatever, but in my own lab, no. I don't know. Sometimes I think they look at me like I'm not doing what they're doing so it's not whatever, or... But I think my advisor thinks I am, but I don't feel like all the time that my counterparts feel that I am. (Avatar)

Despite her prowess as a scholar with a prolific publication record, her physical residence in a computer science space, her engagement in professional computing organizations, and her existence in a community of computer scientists who recognize her as a computer scientist, she still wavers with her claim to the computer science identity. Her identity as a computer scientist was challenged by speculation from her peers on the rigor of her sub-discipline. She did not necessarily have the support of her peers in the community, and thus questioned her positioning in the community.

The only participant in this study who clearly claimed a computer science identity was Janine. As an undergraduate student, Janine participated in several professional organizations,

interned in several places including a top-tier tech company and highly sought-after government agencies, and she had participated in a research summer experience at a prestigious PWI. Her strong involvement in different computer science organizations and her confidence in her coding abilities solidified her identity as a computer scientist: “Computing itself, is just using technology to solve a problem. [...] A computer scientist, is someone who knows how to use the language or so to solve a problem” (Janine). Her approach to computer science was independent of her computer science identity. For her, computer science has been a tool to be utilized to reach an end goal; therefore, her validation in the field has come from a strong sense of reaching those goals, that is, her sense of self-efficacy.

I do computer science as a means to an end. I don't want to be a coder for life. I'm good at writing code, but if I never write code again, I'd be okay with that, but I want to use my ability to write code as a means to an end. I think that's how we should market computer science to Black kids or Black girls. (Janine)

Janine was one of the few participants who had claimed her residency in the computer science community. She described herself as a Black woman computer scientist when others were hesitant to claim that identity.

In this study, the findings demonstrate a significant and alarming phenomenon: that despite their ascension to the highest degree level in computer science, and their participation in a community of practice, the majority of participants rejected or did not acknowledge their identity as computer scientists. The women who participated in this study all recounted experiences in their trajectory that were aligned with the traditional subconstructs related to computer science identity—performance/competence, interest, and recognition. They also ascended to a level of computing/engineering expertise that gained them admission into a competitive computer

science doctoral degree program, and yet they struggled to ascribe the identity of computer scientist to themselves, largely due to their lack of sense of belonging to the broader computer science community. The landscape of computer science (and its accompanying identity) still seemed to be a distant land that they were passing through and thus could not claim residency in. This was an alarming finding, but also posed new questions about their persistence. If a computing identity salience had not been established in most of these women, why and how did they continue to persist? The answer to this question could provide a foundation for future strategies for inclusion and retention.

7. Limitations of the Study

This study includes a single case of a computer science doctoral program with a focus on the Black women matriculating in it. Due to concerns related to deductive disclosure, we did not interview the advisor but instead focused on the perceptions of the participants on the efficacy of the mentoring model leveraged in the bubble, and their understanding of their participation and thus disciplinary identity within this context. Because the case was about the doctoral program (more broadly), we extended our exploration to a student in the program, but not in the bubble. This allowed for a broader view of the case, including the benefits and drawbacks of the bubble structure and the challenges for those outside of the bubble who still self-identify as Black and woman in the program.

Given the scarcity of Black women in computer science doctoral programs, this study was limited by the length and quantity of the interviews. The findings may have been enhanced with an additional interview to further unpack the hesitation to claim a computer science identity.

Likewise, interviews with the advisors and administrators would have provided a clearer view of the intent, execution, and variability of the structures established within this program.

8. Discussion

There were two research questions guiding this study:

Research Question 1: How do Black women graduate students in computer science describe their computer science identity?

Research Question 2: How do landscapes of practice influence computer science identity formation or salience of Black women in a computer science graduate program?

The discussion is presented thematically, in the same fashion as the results—(moments of impact, boundary spanning, and community residence), rather than parsed to align with the questions. This is a deliberate decision driven largely by the complexity of identity. When conducting the study, we asked the participants questions that probed the subconstructs of identity (interest, performance/competence, recognition, and sense of belonging) *and* asked them a direct question related to their claims to a computer science identity. While their answers to the subconstruct questions suggested they perceived themselves as computer scientists, when asked directly, they were split, with the vast majority rejecting the identity. It was through the exploration of their landscapes of practice that we reified the importance of sense of belonging to their identity salience. This study exposes that legitimate participation was not enough (performance/competence), persistence to the highest degree was not enough, and recognition in the field was not enough to identify as a computer scientist. To underscore these findings, we present the themes situated in prior work and close by highlighting our contributions.

The case presented had within its boundaries a bubble (or uniquely designed environment within the larger community of computer science) with the specific intent of supporting African

American students as they negotiated their identity and existence in a computer PhD program. The community was created by following established guidelines for supporting African American students towards the goal of achieving critical mass for minoritized populations in graduate programs to promote retention (Jackson et al., 2013). With so much prior literature pointing to the inequities in STEM graduate programs and computer science more specifically, the fact that Maya was able to create a space that attracted Black women to computer science at a disproportionately higher rate and retained them through to graduation is hard to ignore. This community that she created was supportive, encouraging, and by the metrics of engagement, retention, and graduation rates, successful. The real enigma to this work, however, was the role disciplinary identity played in the persistence of the participants, and furthermore, what role the landscape of practice had on this disciplinary identity salience.

8.1 Moments of Impact

Each participant recounted for us the motivations behind her choice to pursue computer science; these motivations all aligned with prior work—encouragement from family (Fisher et al., 1997), role models in the field (in particular Black female computer science instructors; Black et al., 2011; Maylor, 2009), friends/peers (Cheryan et al., 2009), and interest (Margolis et al., 2000). In fact, the elements such as interest, performance/competence, and recognition (known subconstructs of disciplinary identity) were articulated clearly in their descriptions of how they came to be in a computer science PhD program (Perkins et al., 2020). Given that disciplinary identity has been highly cited as a predictor of persistence in K-16, it is not a surprise to see these subconstructs evidenced in the narratives provided to us by the participants (Taheri et al., 2019).

The participants also talked, at great length, about the importance of opportunities like research experiences for undergraduates on their decision to pursue graduate studies (Minerick,

2008). Likewise, immediate integration into the research group with research projects assigned as soon as they started their graduate journey provided a sense of purpose and contribution, and acted as an opportunity to demonstrate competence in practice (Farnsworth et al., 2016). Active engagement in research both prior to graduate school and then upon arrival allowed the participants to decide to pursue graduate school and persist.

8.2 Boundary Spanning

All the participants discussed how they sought many communities to help them during their transition to graduate school. They sought out racial, ethnic, and gendered communities to aid in the transition into the male-dominated discipline of computer science at their PWI (Ross et al., 2021). They also sought out “traditional” computing communities to validate their claims to a computer science identity. From their recounting, the research group community, in some instances, was not enough.

In some cases, the participants found ways to merge, or at least find planes of overlap, to move fluidly between the many communities of practice, thus creating a landscape of practice. Even though there existed both continuities and discontinuities between the communities, they had the ability to take skills and norms from one community of practice to another (Pyrko et al., 2019). This served as a tactic for coping with the internal struggle of ascribing the identity of computer scientist to oneself. However, there were instances when participants found it best to keep these communities of practice separate and traverse between them, leaving the norms and expectations within the (for example) research group they vacated to enter the broader computer science community. This often created the boundary that limited participation to being a tourist or a sojourner in that space. After all, one’s navigation to and through a multitude of communities is often predicated on their perception of self within the community (Wenger-

Trayner et al., 2015). Instead of assuming the computer science identity, they superficially joined the computing space, but their identities remained unchanged or uninfluenced by their participation in the community of practice due to their perception of *not* being a computer scientist. Likewise, some participants were best described as sojourners in computer science, visitors who were more fully engaged in the community of practice, and whose identity was influenced by the community of practice; however, they still recognized or perceived that their participation did not always result in a full assimilation into the community, thereby rejecting the ability to make claim to the identity of a computer scientist. In the absence of a claim to computer science identity, most found a sense of belonging in their research group (the bubble). They may not have been able to say they were a computer scientist (due to exclusive norms and values of the discipline), but they found a place that affirmed their existence in the sphere of computing—the bubble. While the broader computer science community of practice created an environment, culture, and climate that relegated them to the periphery, their research group provided an opportunity to participate and persist in the field computing in the absence of a computer science identity.

8.3 Community Residence

In spite of efforts by Maya to construct an intersectional community with planes of overlap with the broader computer science community, those planes were fractured, leaving these PhD students without a preserved sense of residence within computer science. The bubble did not account for the ways that the women in this research group defined or measured their competence: earning good grades, passing the required courses, working in labs, advising other students, earning fellowships awards, writing and presenting papers, and participating in other activities that bordered both the landscape of schooling (the activities the students did to achieve

a degree) and the landscape of professional computer scientists. Carlone and Johnson (2007) described the process of identity formation as taking place at two levels. One is how a participant negotiates her identity as a participant in a community of practice, including how her competence is expressed in that community, and whether others recognize her as a member or not. The other way is how the participant's identity is altered through participation in the community. In other words, how does she inherit some of the identity characteristics that reflect the location of her practice in the broader social landscape?

In our study, the intersectional community fosters the first level of identity formation for the participants who shared the targeted social identity (Black women). However, the move across the boundaries of the intersectional community to the broader social landscape is not always smooth. For instance, where the research team would have expected all our participants in the study (as computer science PhD students) to have clearly claimed a computer science identity, we instead discovered that not all the students ascribed that identity to themselves without hesitation. In some cases, they saw their research group as an anomalous safe space that shielded them from the realities of the broader computer science community. This boundary is clearly felt by the participants, as Alexis described the computer science program as their “little Black bubble.” Due to the nature of the program, they often stopped short of claiming to be computer scientists or made their membership in the community contingent on more prestigious recognition (i.e., prestigious fellowships), rather than mere participation in a computer science research community doing computer science research.

The participants' words helped the research team unpack the necessity of bubbles of growth for identity development; however, they also illuminated the need to encourage those who wish to achieve residence in the community to step outside of the bubble into the “more

realistic,” but hostile or “chilly” spaces to aid in the development of a more salient computer science identity. In order to get out of the periphery and join the broader community, some of the participants needed participation in a broader computing community to further strengthen their confidence and identity development. Always being inside the bubble placed limitations on some of the participants’ imaginations with regard to seeing themselves in the broader computing community. Carlone and Johnson (2007) used the concepts of competence, interest, and recognition as proxies for imagining oneself to “belong” in a community. However, a person must have the opportunity to practice what they want to be in the space that aligns with that perception of a role to align that role with their perception of self. As Farnsworth et al. (2016) described, when claims to competence are negotiated in a social context, the boundary of practice can be experienced as peripherality or marginality. If the position is legitimized as peripheral because the person is a perceived newcomer, their claims to competence are accepted as provisional. But if for some reason a community rejects that claim to competence consistently (and after newcomer status), one is susceptible to feelings of marginalization and may decide to actively dis-identify with that learning. If a person has a strong identification with the competence of a community and sees it as a desirable part of their trajectory, then any rejected claims of competence result in a painful experience of marginalization. Interestingly, this study confirms these experiences of marginalization for Black women, but also asserts that identity salience is not always (and in this case, not usually) a necessary component to their persistence. Instead, we found that a true sense of belonging mediated and provided the mitigation necessary to persist without a claim of a disciplinary identity. In this manner, sense of belonging was indicative of persistence for the majority of the participants, but not indicative of a salient computer science identity.

The experience of Avatar, our one Black woman not in the research group, provides a slightly different perspective, as she did not report the sense of belonging, but did describe that she longed for the community and belonging that the intersectional group provided the other participants. Her primary community was the “harsh” computing community, where she felt as if she did not belong despite her successes; this lack of belongingness resulted in the rejection of her computer science identity despite the recognition of her peers and advisor. It is worth noting that she continues to persist in absence of that identity salience and the sense of belonging that her peers experienced.

9. Conclusion

In the case of this research group, an intersectional community of practice had already been developed. The intent was to effectively create a space where underrepresented minorities could feel safe and supported by their peers and mentor(s). The space had all the tenets of success with regards to recruitment (in pairs to battle isolation), support guidelines (course enrollment in pairs to ensure peer support), peer mentoring (racial similarity, guidance, and support), financial support (ease financial burdens/concerns), opportunities for practice (immediate research engagement), and so on. These practices resulted in higher-than-average recruitment, retention, and graduation rate: success. However, the intersectional community of practice, in most cases, did not foster a salient computer science identity for the women. This suggests that the development of communities of practice alone may not be enough to foster a salient disciplinary identity for Black women in computer science. None of this is to say that spaces for URM computing students are a hindrance or should not exist, but instead that they should be complemented with opportunities or encouragement to move beyond those spaces to build

bridges between the two communities. This should be the case, at least, until the broader computer science community better reflects the demographics of the nation.

This study also suggests that identity salience is not a prerequisite for graduate student retention. In fact, it demonstrates that social identity theory falls short in explaining prolonged engagement in computer science. After all, participants in this study were doctoral computer science students and the vast majority did not consider themselves computer scientists. While scholars have long pointed to identity salience for understanding persistence, the results are not as clear in the case of Black women in computing. The participants in this study possess multiple identities (Black, woman, computer scientist) and were thus stratified across complex and oppressive planes. They developed and traversed a landscape of practice composed of Black student organizations, women in science and engineering clubs, and computing professional organizations. They have reached the highest level of education in their field, and yet, their identities as computer scientists are not yet salient. Yet, the women in this study are persisting. Further exploration is necessary to better understand how and why. Future work should include a deeper dive into the applicability of the existing identity frameworks as they pertain to underrepresented groups in computing and related disciplines, perhaps even starting with ontological beliefs related to computing, as it may be that their definitions of what a computer scientist is simply does not align with who they believe they are or can be. Future work might also continue to build on the possibility that a sense of belonging may be a primary predictor of retention and graduation.

This work has implications for research, policy, and practice. On the most basic level, the deliberate adoption of the recruitment and support strategies presented in the case across institutions seems like an obvious first step. While all institutions or departments may not wish to

establish a “Black bubble,” they could make great strides in diversifying their graduate recruitment by actively engaging with and recruiting at HBCUs and HSIs. This should not simply be an effort to poach talent from these institutions; it should be viewed as a strategic relationship that is mutually beneficial to both the minority-serving institution and the PWI. This serves two purposes: (1) it establishes a more diverse recruitment effort; and 2) it will create an opportunity for a moment of impact for a future computer science PhD student. In addition, recruiting graduate students in pairs from minority-serving institutions is another step towards the development of an intersectional community. If an intersectional community is indeed established, it is critical to encourage students to move beyond the boundaries of that safe space to gain access to opportunities to exercise competence in practice in the broader computing community to shift perceptions of self in those spaces. Pushing students to actively engage in organizations like ACM and/or presenting at conferences could provide that opportunity and space to practice their computer science identity.

Computer science education researchers must continue to explore the narratives of the students in the margins if we wish to have real impact in the production of a diverse group of computer science PhDs. Research on computer science norms, values, and practices, as well as the ways in which computer science continues to perpetuate exclusion, must be expanded. Likewise, exploration into ontological beliefs of computer science from various populations could go a long way toward changing the conversation around computer science to bring marginalized populations into the center of the community, so they too can see themselves as computer scientists.

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References

- Anderson-Rowland, M., Bernstein, B., & Felipe Russo, N. (2007). *Encouragers and discouragers for domestic and international women in doctoral programs in engineering and computer science* [Paper presentation]. American Society of Engineering Education Annual Conference and Exposition, Honolulu, HI, United States.
- Arnold, A. C., Wilkins-Yel, K. G., Bekki, J. M., Bernstein, B. L., Natarajan, M., Randall, A. K., Francies, R., & Okwu, C. E. (2020). *Examining the effects of STEM climate on the mental health of graduate women from diverse racial/ethnic backgrounds* [Paper presentation]. American Society of Engineering Education Virtual Annual Conference and Exposition, online. DOI: 10.18260/1-2--34617
- Artis, S., Shavers, M., LeSure, S., Marie Spence, B., & Joshi, A. P. (2018). *Re-framing and reimagining the doctoral student narrative: Black women's experiences in engineering and computer science* [Paper presentation]. American Society of Engineering Education Annual Conference and Exhibition, Salt Lake City, UT, United States.
- Ashford-Hanser, S. (2020). Counter-life herstories: Black women faculty pathways in U.S. P-20 computing education. *Journal of Women and Minorities in Science and Engineering*, 26(5), 447-471. DOI: 10.1615/JWomenMinorScienEng.2020034494
- Berdanier, C., & Zerbe, E. (2018a). *Quantitative investigation of engineering graduate student conceptions and processes of academic writing* [Paper presentation]. Institute of Electrical

and Electronics Engineers International Professional Communication Conference, Toronto, ON, Canada. DOI: 10.1109/ProComm.2018.00037

Berdanier, C. & Zerbe, E. (2018b). *Correlations between graduate student writing concepts and processes and certainty of career trajectories* [Paper presentation]. Institute of Electrical and Electronics Engineers Frontiers in Education Conference, Toronto, ON, Canada. DOI: 10.1109/FIE.2018.8658678

Black, J., Curzon, P., Mykietiak, C., & McOwan, P. W. (2011). *A study in engaging female students in computer science using role models* [Paper presentation]. 16th Annual Conference on Innovation and Technology in Computer Science, Darmstadt, Germany. DOI: 10.1145/1999747.1999768

Burge, J. D., & Suarez, T. L. (2005). Preliminary analysis of factors affecting women and African Americans in the computing sciences [Paper presentation]. Richard Tapia Celebration of Diversity in Computing Conference, Albuquerque, NM, United States. DOI: [10.1145/1095242.1095265](https://doi.org/10.1145/1095242.1095265)

Burt, B. A., Williams, K. L., & Smith, W. A. (2018). Into the storm: ecological and sociological impediments to Black males' persistence in engineering graduate programs. *American Educational Research Journal*, 83, 1–42. DOI: 10.3102/0002831218763587

Carlone, H. B. (2017). Disciplinary identity as analytic construct and design goal: Making learning sciences matter. *Journal of the Learning Sciences*, 26(3), 525–531. DOI: [10.1080/10508406.2017.1336026](https://doi.org/10.1080/10508406.2017.1336026)

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science*

Teaching, 44(8), 1187–1218. [DOI: 10.1002/tea.20237](https://doi.org/10.1002/tea.20237)

Cheryan, S., Plaut, V. C., Davies, P. G., & Steele, C. M. (2009). Ambient belonging: How stereotypical cues impact gender participation in computer science. *Journal of Personality and Social Psychology*, 97(6), 1045–1060. DOI: 10.1037/a0016239

Choe, N. H., Borrego, M., Martins, L. L., Patrick, A. D., & Seepersad, C. C. (2017). *A quantitative pilot study of engineering graduate student identity* [Paper presentation]. American Society of Engineering Education Annual Conference and Exposition, Columbus, OH, United States, . DOI: 10.18260/1-2--27502

Clarke, V., & Braun, V. (2018). Using thematic analysis in counselling and psychotherapy research: A critical reflection. *Counselling and Psychotherapy Research*, 18(2), 107–110. [DOI: 10.1002/capr.12165](https://doi.org/10.1002/capr.12165)

Collins, P. H., & Bilge, S. (2016). *Intersectionality*. Cambridge, UK: Polity Press.

Council of Graduate Schools. (2008). *Ph.D. completion and attrition: Analysis of baseline data from the Ph.D. Completion Project*. The Council of Graduate Schools.

Crenshaw, K. (1989). Demarginalizing the intersection of race and sex: A Black feminist critique of antidiscrimination doctrine, feminist theory and antiracist politics. *University of Chicago Legal Forum*, 1, 139–167.

Creswell, J. (2013). *Qualitative inquiry & research design: Choosing among five approaches*. Sage Publishing.

Cuny, J., & Aspray, W. (2001). *Recruitment and retention of women graduate students in computer science and engineering: Report of a workshop June 20–21, 2000*. The Computer Research Association Committee on the Status of Women in Computing Research. Retrieved from <http://archive.cra.org/reports/r&rwomen.pdf>

- Curry, F. N., & DeBoer, J. (2020). *A systematized literature review of the factors that influence the retention of racially minoritized students in STEM graduate degree programs* []. American Society of Engineering Education Virtual Annual Conference and Exposition, online. DOI: 10.18260/1-2--34069
- Daniels, J., & Brooker, J. (2014). Student identity development in higher education: Implications for graduate attributes and work-readiness. *Educational Research*, 56(1), 65–76. DOI: 10.1080/00131881.2013.874157
- deChambeau, A. L. (2014). *Supported student success: Communities of practice in higher education* (Publication No. 3629604) [Doctoral dissertation, University of Akron]. ProQuest Dissertations and Theses.
- Delgado, R., & Stefancic, J. (2017). *Critical race theory: An introduction* (3rd ed.). New York: University Press.
- Denzin, N. K., & Lincoln, Y. S. (Eds.). (2018). *The SAGE handbook of qualitative research* (5th ed.). SAGE Publications.
- Dou, R., Dabney, K., Sonnert, G., & Sadler, P. (2019). Early informal STEM experiences and STEM identity: The importance of talking science. *Science Education*, 103(3), 623–637. DOI: [10.1002/sce.21499](https://doi.org/10.1002/sce.21499)
- Elfer, K., Rynearson, A. M., Hicks, N. M., Spingola, E. M., & Fair, K. (2017). *Lessons learned: Strategies for creating and mentoring diverse graduate student communities* [Paper presentation]. American Society of Engineering Education Annual Conference and Exposition, Columbus, OH, United States. DOI: 10.18260/1-2--28624
- Exec. Order No. 13780, 3 C.F.R. 13219 (2017). Retrieved from <https://trumpwhitehouse.archives.gov/presidential-actions/executive-order-protecting-nation->

foreign-terrorist-entry-united-states/

- Farnsworth, V., Kleanthous, I., & Wenger-Trayner, E. (2016). Communities of practice as a social theory of learning: A conversation with Etienne Wenger. *British Journal of Educational Studies*, 64(2), 139–160. DOI: [10.1080/00071005.2015.1133799](https://doi.org/10.1080/00071005.2015.1133799)
- Fincher, S., & Robins, A. (2019). *The Cambridge handbook of computing education research*. Cambridge University Press.
- Fisher, A., Margolis, J., & Miller, F. (1997). Undergraduate women in computer science: Experience, motivation and culture. *SIGCSE Bulletin (Association for Computing Machinery, Special Interest Group on Computer Science Education)*, 29(1), 106–110. DOI: [10.1145/268085.268127](https://doi.org/10.1145/268085.268127)
- Godwin, A., Potvin, G., Hazari, Z., & Lock, R. (2013). *Understanding engineering identity through structural equation modeling* [Paper presentation]. Institute of Electrical and Electronics Engineers Frontiers in Education Conference, Oklahoma City, OK, United States. DOI: [10.1109/FIE.2013.6684787](https://doi.org/10.1109/FIE.2013.6684787)
- Google Inc. & Gallup Inc. (2015). *Images of computer science: Perceptions among students, parents, and educators in the U.S.* <https://services.google.com/fh/files/misc/images-of-computer-science-report.pdf>
- Google Inc. & Gallup Inc. (2017a). *Computer science learning: Closing the gap: Rural and small town school districts*. Retrieved from <https://services.google.com/fh/files/misc/computer-science-learning-closing-the-gap-rural-small-town-brief.pdf>
- Google Inc. & Gallup Inc. (2017b). *Encouraging students toward computer science learning*. Retrieved from <https://services.google.com/fh/files/misc/encouraging-students-toward->

computer-science-learning-brief.pdf

- Gubrium, J., Holstein, J., Marvasti, A., & McKinney, K. (Eds.). (2012). *The SAGE handbook of interview research: The complexity of the craft* (2nd ed.). SAGE Publications.
- Gürer, D., & Camp, T. (2002). *Investigating the incredible shrinking pipeline for women in computer science* (Project No. 9812016). National Science Foundation
- Guy, B., & Boards, A. (2019). A seat at the table: Exploring the experiences of underrepresented minority women in STEM graduate programs. *Journal of Prevention & Intervention in the Community*, 47(4), 354–365. DOI: [10.1080/10852352.2019.1617383](https://doi.org/10.1080/10852352.2019.1617383)
- Hall, J. D., O’Connell, A. B., Cook, J. G. (2017). Predictors of student productivity in biomedical graduate school applications. *PLoS One*, 12(1), e0169121. DOI: [10.1371/journal.pone.0169121](https://doi.org/10.1371/journal.pone.0169121)
- Hambrusch, S., Pollock, L., Libeskind-Hadas, R., & Alvarado, C. (2020). *Addressing the national need for increasing the domestic PhD yield in computer science*. Computing Research Association—Education. Retrieved from <https://cra.org/wp-content/uploads/2020/11/Addressing-National-Need-for-Increasing-Domestic-PhD-Yield-in-CS.pdf>
- Jackson, J. F. L., Charleston, L. J., Gilbert, J. E., & Seals, C. (2013). Changing attitudes about computing science at Historically Black Colleges and Universities: Benefits of an intervention program designed for undergraduates, *Journal of African American Studies*, 17(2), 162–173. DOI: [10.1007/s12111-011-9189-7](https://doi.org/10.1007/s12111-011-9189-7)
- Jesiek, B. K., Mazzurco, A., Buswell, N. T., & Thompson, J. D. (2018). Boundary spanning and engineering: A qualitative systematic review. *Journal of Engineering Education*, 107, 380–413. DOI: [10.1002/jee.20219](https://doi.org/10.1002/jee.20219)

- Johnson, R. B., & Christensen, L. (2019). *Educational research: Quantitative, qualitative, and mixed approaches*. Sage Publications.
- Kaiser, K. (2009). Protecting respondent confidentiality in qualitative research. *Qualitative Health Research, 19*(11), 1632–1641. DOI: 10.1177/1049732309350879
- Kajfez, R. L., & McNair, L. D. (2014). *Graduate student identity: A balancing act between roles* [Paper presentation]. American Society of Engineering Education Annual Conference and Exposition, Indianapolis, IN, United States. DOI: 10.18260/1-2--20543
- Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.
- Lewis, A. (2018). *The <1%: Black women obtaining PhDs in computing* [Paper presentation]. Association for Computing Machinery Conference on International Computing Education Research, Espoo, Finland. DOI: [10.1145/3230977.3231016](https://doi.org/10.1145/3230977.3231016)
- Lott, J., Gardner, S., & Powers, D. (2009). Doctoral student attrition in the stem fields: An exploratory event history analysis. *Journal of College Student Retention, 11*(2), 247–266. DOI: [10.2190/CS.11.2.e](https://doi.org/10.2190/CS.11.2.e)
- Lunn, S., Zahedi, L., Ross, M., Ohland, M. (2021). Exploration of Intersectionality and Computer Science Demographics: Understanding the Phenomena Related to Historical Shifts. *ACM Transactions on Computing Education, 21*(2): 1-30. <https://dl.acm.org/doi/10.1145/3445985>
- Margolis, J., Estrella, R., Goode, J., Holme, J. J., & Nao, K. (2010). *Stuck in the shallow end: Education, race, and computing*. MIT Press.
- Margolis, J., Fisher, A., & Miller, F. (2000). The anatomy of interest: Women in undergraduate computer science. *Women's Studies Quarterly, 28*(1/2), 104–127.

- Master, A., Cheryan, S., & Meltzoff, A. N. (2016). Computing whether she belongs: Stereotypes undermine girls' interest and sense of belonging in computer science. *Journal of Educational Psychology, 108*(3), 424–437. DOI: [10.1037/edu0000061](https://doi.org/10.1037/edu0000061)
- Maylor, U. (2009). “They do not relate to Black people like us”: Black teachers as role models for Black pupils. *Journal of Education Policy, 24*(1), 1–21. DOI: 10.1080/02680930802382946
- McCall, G. J., & Simmons, J. L. (1966). *Identities and interactions*. Free Press.
- McGee, E. O., White, D. T., Jenkins, A. T., Houston, S., Bentley, L. C., Smith, W. J., & Robinson, W. H. (2016). Black engineering students' motivation for PhD attainment: Passion plus purpose. *Journal for Multicultural Education, 10*(2), 167–193. DOI: 10.1108/JME-01-2016-0007
- McGrath Cohoon, J., & Aspray, W. (2013). A critical review of the research on women's participation in postsecondary computing education. In *Women and information technology* (pp. 137–180). MIT Press. DOI: 10.7551/mitpress/9780262033459.003.0005
- Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. SAGE Publications.
- Miles, M. L., Brockman, A. J., & Naphan-Kingery, D. E. (2020). Invalidated identities: The disconfirming effects of racial microaggressions on Black doctoral students in STEM. *Journal of Research in Science Teaching, 57*(10), 1608–1631. DOI: [10.1002/tea.21646](https://doi.org/10.1002/tea.21646)
- Minerick, A. (2008). *Advice for new faculty: Structuring a summer REU project and mentoring the participant to a publication* [Paper presentation]. American Society of Engineering Education Annual Conference and Exposition, Pittsburgh, PA, United States. DOI: 10.18260/1-2--4264

- Moneta-Koehler, L., Brown, A. M., Petrie, K. A., Evans, B. J., & Chalkley, R. (2017). The limitations of the GRE in predicting success in biomedical graduate school. *PLoS One*, *12*(1), e0166742. DOI: 10.1371/journal.pone.0166742
- Mooney, C., Antoniadi, A., Karvelas, I., Salmon, L., & Becker, B. A. (2020). *Exploring sense of belonging in computer science students* [Paper presentation]. Association for Computing Machinery Conference on Innovation and Technology in Computer Science Education, Trondheim, Norway. DOI: [10.1145/3341525.3393974](https://doi.org/10.1145/3341525.3393974)
- Mooney, C., & Becker, B. A. (2020). *Sense of belonging: The intersectionality of self-identified minority status and gender in undergraduate computer science students* [Paper presentation]. United Kingdom & Ireland Computing Education Research Conference, Glasgow, Scotland.
- Murray-Thomas, L. (2018). *Jumping over hurdles to get to the finish line: Experiences influencing Black female advanced STEM degree attainment* (Publication No. 10825730) [Doctoral dissertation, California State University, Long Beach]. ProQuest Dissertations & Theses.
- Mwangi, C. A. G., Changamire, N., & Mosselson, J. (2019). An intersectional understanding of African international graduate students' experiences in U.S. higher education. *Journal of Diversity in Higher Education*, *12*(1), 52–64. DOI: 10.1037/dhe0000076
- National Academies of Sciences, Engineering, and Medicine. (2018a). *Assessing and responding to the growth of computer science undergraduate enrollments*. The National Academies Press. DOI: [10.17226/24926](https://doi.org/10.17226/24926).
- National Academies of Sciences, Engineering, and Medicine. (2018b). *Graduate STEM education for the 21st century*. The National Academies Press.
- National Science Foundation, National Center for Science and Engineering Statistics. (2015).

Women, minorities, and persons with disabilities in science and engineering: 2015.

Retrieved from <http://www.nsf.gov/statistics/wmpd/>

Okahana, H., Allum, J., Felder, P. P., & Tull, G. (2016). Implications for practice and research from Doctoral Initiative on Minority Attrition and Completion. *Washington, DC: Council of Graduate Schools.*

Okahana, H., Zhou, E., & Gao, J. (2020). *Graduate enrollment and degrees: 2009 to 2019.* Council of Graduate Schools.

Ong, M. (2011). The status of women of color in computer science. *Communications of the ACM, 54*(7), 32–34. DOI: 10.1145/1965724.1965737

Perez, R. J., Robbins, C. K., Harris, L. W. Jr., & Montgomery, C. (2020). Exploring graduate students' socialization to equity, diversity, and inclusion. *Journal of Diversity in Higher Education, 13*(2), 133-145. DOI: [10.1037/dhe0000115](https://doi.org/10.1037/dhe0000115)

Perkins, H., Bahnson, M., Tsugawa-Nieves, M. A., Satterfield, D. J., Parker, M., Cass, C., & Kirn, A. (2020). An intersectional approach to exploring engineering graduate students' identities and academic relationships. *International Journal of Gender, 11*(3), 440–465. Retrieved from <http://genderandset.open.ac.uk/index.php/genderandset/article/view/679>

Perkins, H., Tsugawa-Nieves, M. A., Chestnut, J. N., Miller, B., Kirn, A., & Cass, C. (2017, June 24–28). The role of engineering identity in engineering doctoral students' experiences [Paper presentation]. American Society of Engineering Education Annual Conference and Exposition, Columbus, Ohio, United States. DOI: 10.18260/1-2--29006

Pyrko, I., Dörfler, V., & Eden, C. (2019). Communities of practice in landscapes of practice. *Management Learning, 50*(4), 482–499. DOI: 10.1177/1350507619860854

Ramirez, E. (2013). Examining Latinos/as' graduate school choice process: An intersectionality

perspective. *Journal of Hispanic Higher Education*, 12(1), 23–36. DOI:
10.1177/1538192712452147

Ridgeway, M., Omotola McGee, E., Naphan-Kinger, D., & Brockman, A. (2018, April 29). *Black engineering and computing doctoral students' peer interaction that foster racial isolation* [Paper presentation]. The Collaborative Network for Engineering and Computing Diversity Conference, Crystal City VA, United States.

Rodriguez, S. L., & Lehman, K. (2017). Developing the next generation of diverse computer scientists: The need for enhanced, intersectional computing identity theory. *Computer Science Education*, 27(3–4), 229–247. DOI: 10.1080/08993408.2018.1457899

Ross, M., Capobianco, B., & Godwin, A. (2017). Re-positioning identity as a viable theoretical framework for studying Black women in engineering. *Journal of Women and Minorities in Science and Engineering*, 23(1), 37–52. [DOI: 10.1615/JWomenMinorScienEng.2017016424](https://doi.org/10.1615/JWomenMinorScienEng.2017016424)

Ross, M., Hazari, Z., Sonnert, G., & Sadler, P. (2020). The intersection of being Black and being a woman: Examining the effect of social computing relationships on computer science career choice. *ACM Transactions on Computing Education*, 20(2), 1–15. [DOI: 10.1145/3377426](https://doi.org/10.1145/3377426)

Ross, M., Huff, J., & Godwin, A. (2021). Resilient engineering identity development critical to prolonged engagement of Black women in engineering. *Journal of Engineering Education*, 110(1), 92–113. DOI: 10.1002/jee.20374

Rynearson, A. M. (2015). *Building a community of practice: Discipline-based educational research groups* [Paper presentation]. American Society of Engineering Education Annual Conference and Exposition, Seattle, WA, United States. DOI: 10.18260/p.23637

Saldaña, J. (2021). *The coding manual for qualitative researchers*. Sage.

- Sax, L. J., Zimmerman, H. B., Blaney, J. M., Toven-Lindsey, B., & Lehman, K. J. (2017). Diversifying undergraduate computer science: The role of department chairs in promoting gender and racial diversity. *Journal of Women and Minorities in Science and Engineering*, 23(2), 101–119. DOI: [10.1615/JWomenMinorScienEng.2017017221](https://doi.org/10.1615/JWomenMinorScienEng.2017017221)
- Siedman, I. (2013). *Interviewing as qualitative research* (4th ed.). Teachers College Press.
- Sowell, R., Allum, J., & Okahana, H. (2015). *Doctoral initiative on minority attrition and completion*. Council of Graduate Schools.
- Stake, R. E. (1995). *The art of case study research*. SAGE Publications.
- Stockard, J., Rohlfing, C., & Richmond, G. (2021). Equity for women and underrepresented minorities in STEM: Graduate experiences and career plans in chemistry. *Proceedings of the National Academy of Sciences*, 118(4), e2020508118. DOI: [10.1073/pnas.2020508118](https://doi.org/10.1073/pnas.2020508118)
- Stryker, S., & Burke, P. J. (2000). The past, present, and future of an identity theory. *Social Psychology Quarterly*, 63(4), 284–297. DOI: [10.2307/2695840](https://doi.org/10.2307/2695840)
- Sverdlik, A., & Hall, N. C. (2018). The PhD Experience: A review of the factors influencing doctoral students' completion, achievement, and well-being. *International Journal of Doctoral Studies*, 13, 361–388. DOI: [10.28945/4113](https://doi.org/10.28945/4113)
- Taheri, M., Hazari, Z., Ross, M. (2019). Exploring computing identity and persistence across multiple groups using structural equation modeling, ASEE 126th Annual Conference and Exposition, June 16 – 19, 2019, Tampa, FL
- Tajfel, H. (1981). *Human groups and social categories: Studies in social psychology*. Cup Archive.
- Tull, R. G., Nino, M. A., & Holmes, K. M. (2014). *Building a community of practice among*

- STEM graduate students to foster academic and professional success* [Paper presentation]. American Society of Engineering Education Annual Conference and Exposition, Indianapolis, IN, United States. DOI: 10.18260/1-2--20128
- U.S. Census Bureau. (2014). *Population division*. Retrieved from <https://data.census.gov/cedsci/table?id=ACS%205-Year%20Estimates%20Data%20Profiles&tid=ACSDP5Y2014.DP05>
- Wenger, E. (1999). *Communities of practice: Learning, meaning, and identity*. Cambridge University Press.
- Wenger-Trayner, E., Fenton-O’Creevy, M., Hutchinson, S., Kubiak, C., & Wenger-Trayner, B. (Eds.). (2015). *Learning in landscapes of practice: Boundaries, identity, and knowledgeability in practice-based learning*. Routledge.
- Winkle-Wagner, R., & McCoy, D. L. (2018). Feeling like an “Alien” or “Family”? Comparing students and faculty experiences of diversity in STEM disciplines at a PWI and an HBCU. *Race Ethnicity and Education*, 21(5), 593–606. DOI: [10.1080/13613324.2016.1248835](https://doi.org/10.1080/13613324.2016.1248835)
- Yardley, L. (2000). Dilemmas in qualitative health research. *Psychology and Health*, 15, 215–228. <http://doi.org/10.1080/08870440008400302>
- Zweben, S., & Bizot, B. (2020a). 2019 Taulbee Survey: Total undergrad CS enrollment rises again, but with fewer new majors; doctoral degree production recovers from last year’s dip. *Computing Research News*, 32(5), 3–63. Retrieved from <https://cra.org/crn/2020/05/2019-taulbee-survey/>
- Zweben, S., & Bizot, B. (2020b). 2020 Taulbee Survey: Bachelor’s and doctoral degree production growth continues but new student enrollment shows decline. *Computing Research News*, 33(5), 1–67. Retrieved from <https://cra.org/crn/2021/05/2020-taulbee->

survey/