Bolstering the Persistence of Black Students in Undergraduate Computer Science Programs: A Systematic Mapping Study

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Background: People who are racialized, gendered, or otherwise minoritized are underrepresented in computing professions in North America. This is reflected in undergraduate computer science (CS) programs, in which students from marginalized backgrounds continue to experience inequities that do not typically affect White cis-men. This is especially true for Black students in general, and Black women in particular, whose experience of systemic, anti-Black racism compromises their ability to persist and thrive in CS education contexts.

Objectives: This systematic mapping study endeavours to (1) determine the quantity of existing non-deficit-based studies concerned with the persistence of Black students in undergraduate CS; (2) summarize the findings and recommendations in those studies; and (3) identify areas in which additional studies may be required. We aim to accomplish these objectives by way of two research questions: (RQ1) What factors are associated with Black students' persistence in undergraduate CS programs?; and (RQ2) What recommendations have been made to further bolster Black students' persistence in undergraduate CS education programs?

Methods: This systematic mapping study was conducted in accordance with PRISMA 2020 and SEGRESS guidelines. Studies were identified by conducting keyword searches in seven databases. Inclusion and exclusion criteria were designed to capture studies illuminating persistence factors for Black students in undergraduate CS programs. To ensure the completeness of our search results, we engaged in snowballing and an expert-based search to identify additional studies of interest. Finally, data were collected from each study to address the research questions outlined above.

Results: Using the methods outlined above, we identified 16 empirical studies, including qualitative, quantitative, and mixed-methods studies informed by a range of theoretical frameworks. Based on data collected from the primary studies in our sample, we identified 13 persistence factors across four categories: (I) social capital, networking, & support; (II) career & professional development; (III) pedagogical & programmatic

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interventions; and (IV) exposure & access. This data-collection process also yielded 26 recommendations across six stakeholder groups: (i) researchers; (ii) colleges and universities; (iii) the computing industry; (iv) K-12 systems and schools; (v) governments; and (vi) parents.

Conclusion: This systematic mapping study resulted in the identification of numerous persistence factors for Black students in CS. Crucially, however, these persistence factors allow Black students to persist, but not thrive, in CS. Accordingly, we contend that more needs to be done to address the systemic inequities faced by Black people in general, and Black women in particular, in computing programs and professions. As evidenced by the relatively small number of primary studies captured by this systematic mapping study, there exists an urgent need for additional, asset-based empirical studies involving Black students in CS. In addition to foregrounding the intersectional experiences of Black women in CS, future studies should attend to the currently understudied experiences of Black men.

CCS Concepts: • **Applied computing → Education;** • **Social and professional topics → Computing education**; **Race and ethnicity**;

Additional Key Words and Phrases: Black students in computer science, anti-Black racism in computer science, equity in computer science education, Equity Diversity Inclusion

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1 INTRODUCTION

Despite the proliferation of outreach initiatives designed to bolster diversity in computing (e.g., [1–3]), computing professions in North America remain overwhelmingly men, White, and generally lacking in diversity [4–10]. This is reflected in undergraduate and graduate **computer science (CS)** programs, in which students who are racialized, gendered, or otherwise minoritized tend to be underrepresented [11]. Computer science includes several fields such as networks, artificial intelligence, computer-human interface, gaming, and software engineering. In CS education, disparities in representation are especially pronounced for students who are Indigenous or Black, and amplified further for those identifying with intersecting, marginalized identities [8, 10–12]. It is important to note, however, that equity cannot be reduced to mere numerical representation [13], and that these disparities are indicative of a more fundamental problem. Namely, that individuals who are racialized, gendered, or otherwise minoritized continue to experience inequities in a variety of CS educational contexts [7, 9, 14–19].

The culture of CS privileges Whiteness, the systemic reproduction of which is obscured by colour-evasive and meritocratic ideologies and their attendant discourses [7, 9, 17, 20–24]. Though this culture is problematic for racialized students from a variety of backgrounds, it creates an especially hostile environment for Black students in general, and Black women in particular, whose ongoing experience of systemic, anti-Black racism compromises their ability to persist and thrive in CS programs and professions [5, 24–26]. In addition to having to overcome the exclusionary culture of CS, Black students must contend with a number of additional systemic barriers. On average, Black CS students' access to financial resources tends to be more limited than that of their non-Black counterparts. In 2016, for instance, 31% of Black children in the United States experienced poverty, compared to 10% of White children [27]. Owing to systemic anti-Black racism in society more broadly, moreover, Black students are more likely to attend poorly funded schools [7]. Consequently, Black students may have relatively limited access to technologies, as well as fewer opportunities for advanced engagement with computing in formal (i.e., in-school course offerings) and informal (e.g., after-school computing clubs) educational contexts [28–30]. Owing to these systemic issues, Black CS students may also struggle to relate to their non-Black peers and educators, resulting in feelings of social or academic isolation [7]. Besides, Black women usually feel completely isolated in the CS field [89].

Though each of the systemic barriers outlined above have been the subject of empirical studies, there is currently a lack of systematic reviews focused specifically on non-deficit-oriented approaches to bolstering the persistence of Black students in undergraduate CS programs. Accordingly, this systematic mapping study endeavours to address this gap by illuminating the current state of the extant literature and identifying avenues for further study by way of the following research questions:

- (RQ1) What factors are associated with Black students' persistence in undergraduate CS programs?
- (RQ2) What recommendations have been made to further bolster Black students' persistence in undergraduate CS education programs?

Note that a systematic mapping study is a form of systematic review that does not aim at synthesizing the literature, but rather focuses on categorizing primary studies against a given framework/model, to identify the relevant research that has been undertaken in an area and to identify potential gaps in that research area [96].

1.1 Rationale and Significance

In CS programs and professions—as in **science, technology, engineering, and mathematics (STEM)** fields more generally—the underrepresentation of marginalized people is often framed in terms of a metaphorical leaky pipeline (e.g., [4, 6, 7, 11, 20, 31]). According to this metaphor, racialized and gendered students are more likely than their White, cis-male counterparts to 'leak out' of the STEM pipeline. These students are especially prone, on this view, to opt out of classes which serve as prerequisites to degrees and careers in STEM. This metaphor is problematic, however, because it implies that marginalized students *passively* leak out of the pipeline rather than being *actively* filtered out of the same [32]. This metaphor also elides the existence of systemic inequities [33], thereby lending itself to deficit-based understandings of inequitable educational processes [16, 34]. When viewed through a deficit lens, racialized and gendered students are underrepresented in STEM not because of systemic inequities, racial injustices, or cultures of exclusion, but because they are deficient as people and students. In effect, this amounts to systemic victim blaming [7, 9, 15, 16, 22, 34–37].

In line with the above, diversity initiatives in CS are often justified with reference to the apparent need to address a talent deficit or labour shortage in the workforce (e.g., [38–40]). This is problematic, as Sepehr Vakil [41] notes, because "linking the need for CS in schools to the interests of multinational corporations obscures the sociopolitical implications, relevance, and, ultimately, liberatory possibilities of teaching and learning CS" (p. 27). Gabriel Medina-Kim [21] contends, along similar lines, that this manner of framing the problem is inherently exploitative and assimilationist. Marginalized students are understood, on this view, not only as an "untapped resource to fill employment demands", but also as resources whose "essential difference [...] must be incorporated to improve problem solving, product design, and 'the health and vitality of science and engineering'" (p. 3). When diversity initiatives are reduced to instruments for addressing labour shortages, in other words, the focus of these initiatives invariably shifts away from the need to address systemic inequities, and towards the need to assimilate marginalized students.

The significance of this study, in light of the context established above, should be understood not in terms of economics, but in terms of justice. After all, for people who are racialized, gendered, or otherwise minoritized, the lack of diversity in CS professions can have significant consequences [10]. As Safiya Noble has noted, for instance, the lack of diversity in CS means that algorithms are liable to reinforce negative stereotypes associated with racialized or gendered peoples [42]. Similarly, Algorithmic Justice League founder Joy Buolamwini has illuminated the gender- and race-based biases embedded in facial recognition software [43, 44]. As Yolanda Rankin and Kallayah Henderson have shown, moreover, speech-based interfaces and digital assistants like Siri or Alexa are designed in a manner which reinforces whiteness and perpetuates anti-Black racism [45]. In effect, as Ruha Benjamin argues in the context of algorithmic computations of health risk, digital technologies are increasingly automating racism, and this is sometimes a matter of life and death [101]. Simply put, the underrepresentation of Black people in CS professions has significant, real-world consequences for Black communities in North America and beyond, and even for the development of future technologies. Accordingly, we position this systematic mapping study as a justice-centered intervention [18, 21, 41, 46] which strives to contribute to efforts to bolster Black students' ability to persist and thrive in CS programs and professions.

Despite the specificity of the issues outlined above, however, researchers often lump Black students together with students from underrepresented backgrounds more generally (e.g., [47–49]). Similarly, researchers sometimes group Black women together with 'women of colour' more generally (e.g., [17, 38, 40]), thereby obscuring the particular effects of intersectionality on the experiences of Black women in CS [5, 50]. Furthermore, though some studies engage specifically with Black students in CS programs, researchers often lump these participants together with Black students in related STEM programs, such as engineering (e.g., [51–53]). We believe it is important, however, to attend to the particularities of CS programs and professions. Though some researchers have focused specifically on Black students in CS programs or professions, these studies often take a deficit-based approach to framing or addressing the underrepresentation of Black people in computing (e.g., [54–56]). Deficit-based studies are particularly problematic, as noted above, because they focus on the supposed deficiencies of underrepresented students to the exclusion of systemic factors. That is, deficit-based studies are premised on a fundamental misunderstanding of the causes of underrepresentation [22, 35, 36]. Asset-based studies focus, by contrast, on how best to leverage the strengths of marginalized students and their families with a view towards bolstering their persistence in the face of systemic educational inequities [12, 14, 16, 31, 37, 57, 58]. There exists an urgent need, in other words, to identify, foreground, and amplify existing, asset-based studies engaging principally with Black students in undergraduate CS contexts. This systematic mapping study endeavours to address this gap in the literature.

1.2 Research Objectives

In line with the above, we conducted this systematic mapping study with three objectives in mind: (1) to determine the quantity of existing, non-deficit-oriented studies concerned with the persistence of Black students in undergraduate CS; (2) to summarize the findings and recommendations provided by those studies; and (3) to identify areas in which additional studies may be required.

1.3 Related Work

Though no existing work has systematically mapped the literature using the specific parameters outlined above, we discuss in this section a handful of related work.

First, and perhaps the most closely related to the present study, is a systematic mapping study by London et al. [59] exploring "the salient characteristics of literature (empirical or otherwise) on broadening the participation of African Americans in engineering and computer science" (p. 201). Despite the subject matter overlap, London et al.'s systematic mapping study differs from the present study in several respects. Whereas the present study focuses on Black students' experiences in undergraduate CS programs, for instance, London et al. focuses not only on CS education, but also on engineering and STEM education from K-12 to graduate school and beyond. As noted above (see Section 1.1 Rationale and Significance), however, we believe it is important to attend to the particular systemic barriers faced by Black students in CS undergraduate educational contexts. Though systematic mapping studies are expected to provide broad coverage of the subject under study, we contend that the importance of specificity in this instance is such that a narrower disciplinary focus is required. Similarly, London et al.'s eligibility criteria stipulate that empirical studies need only include "African Americans in the population", and that non-empirical studies in which "broadening participation [is] the focus" are also eligible (p. 207). In doing so, London et al. concede, "the specific needs and experiences of the population as well as within-group variability may be lost in the larger sample" (p. 227). Along similar lines, London et al.'s sample included a total of 470 papers, only 40 of which dealt specifically with CS. This is not to suggest, of course, that London et al.'s systematic mapping study is not valuable. Indeed, London et al.'s systematic mapping study offers a number of valuable insights. We argue, however, that the present study makes a distinct contribution to the field by virtue of its narrower focus, which generated material differences in our findings.

Second, Smarr and Gilbert [60] conducted a systematic literature review examining diversity initiatives geared towards Black students in undergraduate computing contexts, with a particular emphasis on the theoretical frameworks used (or not) to inform these initiatives. In line with the present study, Smarr & Gilbert specifically included studies focused on Black students in undergraduate computing and excluded those concerned with STEM education in general. A total of 36 papers met Smarr & Gilbert's eligibility criteria. Smarr & Gilbert divided these papers into four categories: (1) program; (2) experience; (3) course development/structure; and (4) tools. It appears as though this literature review is a work in progress, however, as this conference paper only reported on the results associated with the course development/structure category. In addition, Smarr & Gilbert provided limited details concerning their methodological approach (e.g., search terms are not provided), potentially compromising the reproducibility of their findings as a result. Nevertheless, Smarr & Gilbert ultimately found that "the field could benefit from intentional cultural considerations in the development and evaluating of computing [curricula]" (p. 7).

Third, Morales-Chicas et al. [61] conducted a systematic literature review to examine "**culturally responsive education (CRE)** tools and strategies within K-12 computing education" with an emphasis on those capable of generating equitable outcomes for students from marginalized backgrounds (p. 125). A total of 22 papers met Morales-Chicas et al.'s eligibility criteria. Using a narrative synthesis approach to code these papers, Morales-Chicas et al. identified six distinct CRE strategies: (1) sociopolitical consciousness raising; (2) heritage culture through artifacts; (3) vernacular culture; (4) lived experiences; (5) community connections; and (6) personalization.

Fourth, Batten & Ross [62] conducted a systematic literature review with a view towards "understand[ing] the current state of social constructivist pedagogies and their educational interventions in post-secondary computer science education and their effects at the intersection of race, gender, and ethnicity" (p. 4). A total of 14 papers met Batten & Ross's eligibility criteria. Ultimately, Batten & Ross found that though individual pedagogical interventions and "collaborative course offerings" may result in improved "learning experiences, learning outcomes, retention, and persistence [for] minoritized women in computing", these interventions are most effective when paired with "larger changes to the overall culture of the computing classroom" (pp. 24-25).

In sum, existing systematic literature reviews have examined the persistence of Black students in CS, but only indirectly – that is, by including studies which also involved non-Black students and/or non-CS programs. The present study endeavours to address this gap by focusing specifically on non-deficit-based empirical studies involving Black students in undergraduate CS programs.

1.4 Positionality Statements

In an attempt to account, to the greatest degree possible, for the countless "seen, unseen, and unforeseen dangers" [63] associated with educational studies in general, and those concerned with sensitive racial and cultural issues in particular, we aim in this section to engage in critical self-reflection by positioning ourselves in relation to the subject of anti-Black racism in CS education. In short, though we are a racially-, culturally-, and disciplinarily-diverse group of authors, educators, and researchers, we are united in our shared commitment to combatting anti-Black racism in CS education and beyond. What this commitment entails, however, differs based on our respective positionalities, as detailed below.

Alvine B. Belle: I am a Black woman of African descendants. I hold a Ph.D. in computing (software engineering) from University of Quebec (Ecole de Technologie Supérieure), a Canadian University. I have completed a 2-year industrial postdoctoral fellowship in software engineering at the University of Ottawa (Canada). After completing my postdoctoral fellowship, I worked for more than two years for the federal public service of Canada while completing a graduate diploma in public administration and governance at McGill University (Canada). I am currently working as an assistant professor in the Department of Electrical Engineering and Computer Science at Lassonde School of Engineering (York University). Due to my cultural background, I have faced some challenges when completing my undergraduate and graduate studies, and when pursuing some jobs opportunities. Some of my relatives and friends belong to minoritized groups and have faced similar challenges too. Luckily, I had access to several resources (e.g., a large pool of mentors, a supporting community made of relatives and friends, financial support) that helped me efficiently tackle these barriers and allowed me to persist in the computing area, first as a student, then as a computer scientist. I am a strong advocate of EDI (Equity, Diversity, and Inclusion) principles. I am very grateful to now have the opportunity to teach and supervise students from very diverse backgrounds. My contribution to this paper is to investigate and disseminate —from a computer scientist and educator perspective — success enablers for Black students in general and for Black women students in particular.

Callum Sutherland: I am a White, able-bodied, cis-gender man and settler of British and German descent. I was born, raised, and have spent most of my life on Treaty 13 territory, in what is now known as Toronto, Canada. From a young age, I internalized—through public education—a false sense of evasiveness with respect to race and culture. Consequently, it was not until many years later, when I started graduate school, that I found myself capable of perceiving systemic White privilege. Today, I am deeply committed to engaging in ethical allyship by contributing to (and not co-opting) projects advancing the causes of **Equity, Diversity, and Inclusion (EDI)** as well as decolonization and Indigenization. In light of my privilege and positionality, of course, I have no first-hand understanding of the embodied experience of discrimination. Accordingly, my career as a social sciences researcher has been driven by my interest in critical, qualitative, participatory research methods designed to foreground marginalized perspectives on, and experiences with, science and technology in society. Thus, my contribution to this paper should be understood not as that of an expert on the experiences of Black students in computer science, but as that of an ally in coalition with the lead author's efforts to combat anti-Black racism in computer science education.

Opeyemi O. Adesina: I identify as a Black-African (originally from the South-Western region of Nigeria) man with Computer Science education and qualifications (i.e., bachelors, masters, and doctorate). I migrated to Canada in 2013 as a doctoral student – specifically at the University of Ottawa; postdoctoral education at David Cheriton School of Computing, University of Waterloo. I currently hold a tenure-track Assistant Professor position at the School of Computing, University of the Fraser Valley. In my capacity, I have been privileged to teach culturally diverse students (including Blacks and white, as well as men and women), and as typical for any Canadian society. Consequently, I have experienced a few challenges due to my cultural origin. For the past 3 years, I have taught under 8% Black students in each of my classes. Personally, I am committed to the principles of Equity, Diversity, and Inclusion. Thus, my courses and projects are designed (and annually reviewed) to reflect cultural backgrounds and beliefs of my students/participants as well as my practices as an academic (even in relating with my colleagues).

Segla Kpodjedo: I am a Black-African from African Descendants. I have completed my masters, and doctorate degrees in computing at Ecole de Polytechnique de Montreal (Canada). I am currently working as an associate professor in computing at the Ecole de Technologie Superieure (Canada). I am committed to the principles of Equity, Diversity, and Inclusion. As a professor, I have supervised several students belonging to diverse social, cultural and economic statuses and devised several means to help them succeed in their computing programs. I am aware that, due to the environmental culture among others, systemic racism and anti-Blackness, Black students may sometimes be perceived as the ones who do not have the skills to persist and succeed in computing programs. So, less effort and care are usually dedicated to their education and/or supervision. For instance, some professors are reluctant to supervise Black students. So, Black students often struggle to find professors to supervise their computing projects. And even when they do, some of these professors neglect them, assuming it is a waste of time to nurture them, especially since, due to the glass ceiling, stereotypes and bias result in perceptions that Black students are not usually expected to ascend the computing career ladder once they have graduated. Black students, therefore, need caring mentors and role models to inspire them, instill confidence in them, and provide them advice to properly navigate through their respective academic and future career pathways. However, Black students usually struggle to find such mentors/role models since, due to the systemic inequities that are prevalent in computing fields, there are only a few of them. My contribution to this paper is therefore to explore how these long-held beliefs impact black students enrolled in computing programs and to devise solutions to dismantle these beliefs to efficiently foster the success of Black students in computing.

Nathanael Ojong: I am a Black-African. I work as an Assistant Professor of International Development Studies at York University. I am also the Deputy Director of the Harriet Tubman Institute for Research on Africa and its Diasporas at York University (Canada). I am a member of the Knowledge Network of African Experts established by the United Nations Office of the Special Adviser on Africa to help shape economic and social policy in Africa. My research analyzes the complex social, cultural, and economic forces that are influencing the adoption, use, acceptance and diffusion or rejection of off-grid solar technologies in sub-Saharan Africa. I am committed to the principles of Equity, Diversity, and Inclusion. As a social sciences researcher, I strive at relying on these principles to explore solutions to help students from underrepresented groups, including Black students, to succeed in their education.

Lisa Cole: I am an Asian woman from South Korea. I am currently working as the Director of Programming for Lassonde's Kindergarten to Industry Academy (k2i). I am an award-winning physics educator who is passionate about creating accessible and equitable learning opportunities in STEM. I have experience within the K-12 education sector including leadership in Science and Technology curriculum in public school boards, president of the Ontario Association of Physics Teachers, and policy at the Ontario Ministry of Education. As a member of the Canada Learning Code Board of Directors, I strive at creating opportunities for those most disadvantaged in the field of Computer Science in Canada.

1.5 Structure

The remainder of this paper is structured as follows. In Section 2, Methodology, we detail our methodological approach to conducting this systematic mapping study. In Section 3, Results, we describe the various findings that emerge from this study. In Section 4, Discussion, we discuss our interpretation of the results, in addition to offering recommendations to guide future studies. In Section 5, Other information, we disclose additional information relevant to the completion of the study. Finally, in Section 6, Conclusion, we briefly summarize our findings and recommendations, in addition to offering concluding remarks.

2 METHODOLOGY

The **PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses)** [65, 105] reporting guideline has been widely adopted in various areas including healthcare, social sciences, education, and computer science [103]. PRISMA yields a more concise and transparent reporting than other reporting guidelines [104]. Its most recent version is PRISMA 2020: it results from the consensus of more than one hundred systematic review methodologists and journal editors across the world [105]. We therefore designed and carried out this systematic mapping study in accordance with Petersen et al.'s [64] guidelines for conducting systematic mapping studies in software engineering; Page et al.'s [65] PRISMA 2020 guidelines; and **SEGRESS (Software Engineering Guidelines for REporting Secondary Studies)**, Kitchenham et al.'s [66, 67] adaptation of the PRISMA 2020 guidelines for secondary research in software engineering that addresses some of PRISMA 2020 limitations.[1] For example, in titling this paper, writing the abstract, and structuring the introduction, we followed the "Title", "Abstract", and "Introduction" sections of the SEGRESS checklist, SEGRESS checklist [66], which correspond with items 1, 2, and 3–4 of the PRISMA 2020 checklist [65]. Along similar lines, in writing the results and discussion sections of this paper, we followed the "Results" and "Discussion" sections of the SEGRESS checklist [66], which correspond with items 16–22 and 23–27 of the PRISMA 2020 checklist [65]. In line with the above, we endeavour in this section to detail the procedures we followed in conducting this systematic mapping study. In doing so, we followed the "Methods" section of the SEGRESS checklist [66], which corresponds to items 5–15 of the PRISMA 2020 checklist [65]. We also checked compliance with these reporting guidelines by relying on existing compliance frameworks (e.g., [84]). Five members of the research team developed/revised the different versions of the protocol used in this systematic mapping study until the most optimal one was defined. Two members of the team also made several checks at each key phase of the study to ensure the protocol was properly followed throughout the completion of study.

2.1 Eligibility Criteria

There exists an urgent need, as we have argued, to attend to the specificities associated with the experiences of Black students in undergraduate CS programs. To that end, we designed our inclusion and exclusion criteria (see Table 1) with a view towards identifying, foregrounding, and amplifying non-deficit-based empirical studies engaging with Black students in undergraduate CS contexts.

Beginning with the inclusion criteria: First, because English is the language in which all members of the research team are fluent, we opted only to include papers written in English. Second, we opted to include papers published as far back as 2001 to test our hypothesis that the vast majority of non-deficit-based studies focused specifically on Black students in undergraduate CS programs have been published in the past 10 years. Third, in line with our objectives outlined above, we opted only to include papers containing primary research results. During the search process, it

[1]For instance, the SEGRESS Abstract Checklist [66, 67] is derived from the PRISMA 2020 Abstract Checklist but does not consider items 11 and 12 of the PRISMA 2020 for abstracts checklist because these items do not apply to the software engineering field.

Table 1. Inclusion and Exclusion Criteria

Inclusion criteria	**Exclusion criteria**
• The paper is written in English.	• The paper is a book, book chapter, and/or was not subject to peer review.
• The paper was published in 2001 or later.	• The paper is broadly concerned with STEM or engineering education, and undergraduate computer science or computing is not the principal focus.
• The paper contains primary research results.	• The paper is broadly concerned with students who are racialized, gendered, or otherwise minoritized, but Black students are not the principal focus.
• The paper presents findings capable of informing efforts to bolster the persistence of Black students in undergraduate computer science or computing programs.	• The paper employs a deficit-based approach to framing or addressing the underrepresentation of Black students in undergraduate computer science or computing programs.

should be noted, we made note of all literature reviews which satisfied most or all the remaining eligibility criteria. These papers were addressed in Section 1.3, Related Work. Fourth, rather than only including studies involving current undergraduate students, we broadened this inclusion criterion to permit the inclusion of studies engaging with former undergraduate students as well. For example, it is doubtless that Rankin et al.'s [7] "Black Women Speak: Examining Power, Privilege, and Identity in CS Education" contains findings capable of informing efforts to bolster the persistence of Black students in undergraduate CS programs. However, only one of Rankin et al.'s 24 participants is an undergraduate student. The other 23 participants include academics, professionals, and graduate students, each of whom offer insights concerning their experiences in undergraduate computing programs. Thus, we broadened the fourth inclusion criterion to ensure that we would be able to capture insightful studies like this one in our sample.

Turning to our exclusion criteria: First, as we are primarily interested in papers published in peer-reviewed journals, we opted to exclude books, book chapters, and papers not subject to peer review. This is not to suggest, of course, that books do not contain insights capable of bolstering the persistence of Black students in undergraduate CS or computing programs. Rather, this first criterion is reflective of our interest in the current state of this literature in peer-reviewed journal and conference papers. We acknowledge, however, that this exclusion criterion may result in the exclusion of important accounts by Black authors. Consequently, we may have reproduced the very exclusionary practices we hope to stand against. Accordingly, we plan to revisit this dimension of the literature in a future study. Second, in keeping with our commitment to specificity (see Section 1.1, Rationale and Significance), we opted to exclude papers in which undergraduate CS education was not the principal focus (e.g., [51–53]). Third, along similar lines, we excluded papers that were not principally focused on Black students (e.g., [47–49]). That is, Black students did not have to comprise the entirety of the researchers' sample, but they had to be the primary focus.

Finally, we excluded studies taking a deficit-oriented approach to framing or addressing the underrepresentation of Black students in undergraduate CS or computing programs. As noted above, deficit-oriented studies are those that are predicated on the assumption that Black students are underrepresented in STEM fields because they are missing *something*, such as a lack of motivation, intelligence, literacy, interest, or information [34]. Accordingly, deficit-oriented studies typically assess the effectiveness of interventions designed to address these apparent deficiencies. To assess whether a given study was deficit-oriented, we employed Shaun Harper's anti-deficit framework for research involving students of colour [97]. That is, if a given paper's research questions more closely resembled Harper's [97] sample of deficit-oriented questions than they did the associated

Table 2. Databases Searched during the First Phase of this Study

#	Database	URL
1	ACM Digital Library	http://dl.acm.org/
2	IEEE Xplore	http://ieeexplore.ieee.org/
3	Engineering Village	http://www.engineeringvillage.com/
4	Scopus	https://www.scopus.com/
5	EBSCOhost Web	http://search.ebscohost.com/community.aspx
6	ERIC (via ProQuest)	https://about.proquest.com/en/products-services/eric/
7	APA PsycInfo (via ProQuest)	https://proquest.libguides.com/psycinfo

anti-deficit reframing, we classified the paper as a deficit-oriented study. For example, Cummings et al. [68] assess whether a conversational agent and virtual mentor is capable of increasing Black undergraduate students' interest in pursuing professorships. At issue for Cummings et al., in other words, is the question: *Why do so few Black students pursue professorships in STEM fields?* This question more closely resembles one of Harper's [97, p. 68] deficit-oriented sample questions (i.e., "Why do so few Black male students enroll in college?") than it does the corresponding anti-deficit reframing of this question (i.e., "How were college aspirations cultivated among Black male undergraduates who are currently enrolled?"). In other words, an anti-deficit reframing of Cummings et al.'s question would read something like: *How were professorial aspirations cultivated among Black male professors in STEM fields?* Accordingly, Cummings et al. [68] was excluded during the database-driven search described below. Ultimately, three papers were excluded by virtue of having been classified as deficit-oriented studies: one during the database search phase, and two during the snowballing phase.

It should be noted that both the inclusion and exclusion criteria were applied sequentially, from top to bottom. For this reason, not every paper was assessed for its ability to inform efforts to bolster the persistence of Black students in undergraduate computing programs because many papers failed to satisfy the preceding inclusion criteria. If a paper was published in 1999, for instance, there was no need to assess whether it satisfied this more stringent criterion. Along similar lines, if a paper was not peer reviewed, there was no need to assess whether it qualified as a deficit-oriented study. As such, the true number of deficit-oriented studies excluded during this review was likely much higher.

2.2 Information Sources

To capture studies from a range of disciplines with the potential to satisfy the eligibility criteria outlined above, we selected a total of seven databases (see Table 2) in which to conduct keyword searches. We selected these databases with a view towards ensuring broad coverage of papers in the fields of computing (ACM Digital Library), engineering (IEEE Xplore and Engineering Village), science (Scopus), psychology (APA PsycInfo), and education or social sciences (EBSCOhost Web and ERIC).

In addition to the databases listed above, we used Connected Papers (https://www.connectedpapers.com/) to snowball records meeting the eligibility criteria. Connected Papers is a very performant tool that supports the implementation of robust search strategies [91] and that is increasingly used by the scientific community to perform snowballing. As Solomons [91] points out, Connected Papers is very efficient at finding strongly connected studies by leveraging a similarity metric that exploits the concepts of Co-citation and Bibliographic Coupling. We therefore deemed it appropriate to perform snowballing during our search. After snowballing, we used a computer science bibliography website called DBLP[2] (https://dblp.org/) to assess the completeness of our search by cross-referencing the digital libraries of two experts identified during our search against the eligibility criteria. We also contacted experts to ask them to assess our list of studies and to suggest additional studies we may have missed. Following Harry Collins [100], we define experts for the purposes of this study not as generalists but as specialists – that is, as the small handful of researchers—i.e., the 'core set'—who are at the cutting edge of research into a particular research problem. The experts in the context of this study, in other words, are either: (1) the most prolific asset-oriented researchers on the persistence of Black students in undergraduate CS programs; or (2) high-profile researchers specialized in diversity in the computing area. Ultimately, however, no papers were added to our sample through the expert-based searches.

2.3 Search Strategy

In searching the databases listed above, we employed the following Boolean search string, which consists of three sets of keywords joined by the "AND" operator:

```
("black students" OR "black people" OR "black women" OR "black
females" OR "black men" OR "black males") AND ("computer science"
OR "computer science education" OR "CS" OR "CS education" OR
"computing") AND (success OR achievement OR underrepresentation OR
participation OR equity OR diversity OR inclusion OR "asset based"
OR persist*)
```

We designed this search string with a view towards striking an optimal balance between the need to attend to the specificity of the subject matter on the one hand, and our desire to 'cast a wide net' with our search on the other. With that in mind, we structured the first set of keywords with specificity in mind by ensuring that the records returned included specific references to Black students. The second and third set of keywords were designed to cast a much wider net. For example, even though the second set of keywords were designed to capture CS-centric records, we opted not to pair these keywords with terms like "college", "university", or "higher education" to ensure that, say, studies engaging with current computing professionals would be captured as well (see Section 2.1, Eligibility Criteria). Along similar lines, the third set of keywords includes a range of terms variously used in equity-, diversity-, and inclusion-oriented and asset-based studies. Taken together, we believe we struck an appropriate balance between specificity and breadth.

We conducted keyword searches in our chosen databases on October 5, 2022. As each of our chosen databases has its own interface, features, and optional parameters, the search terms listed above had to be adapted accordingly, as summarized by Table 3. To verify the reproducibility of our database-driven search, we consulted this table to complete the search again on October 28, 2022, yielding identical results in the process.

In addition to the parameters outlined above, it should be noted that we opted to use advanced search functions where available. We searched within abstracts for each database save for IEEE Xplore, where an abstract search returned limited results. For this reason, we searched IEEE Xplore using metadata. We considered completing metadata searches for the other databases as well but discovered that the other databases did not offer this functionality. To ensure reproducibility beyond 2022, we limited search results by publication date from 2001 to 2022. Where permitted to specify the month, we limited search results by publication date from January 2001 to October 2022. We also specified additional parameters which corresponded with our eligibility criteria (e.g., limiting search results to peer reviewed papers, excluding books, etc.) wherever available.

[2]Digital Bibliography & Library Project.

Table 3. Queries and Parameters used to Search Each Database

Database	Query/search terms	Database-specific parameters
ACM Digital Library	`Abstract: ("black students" OR "black people" OR "black women" OR "black females" OR "black men" OR "black males") AND Abstract:("computer science" OR "computer science education" OR "CS" OR "CS education" OR "computing") AND Abstract: (success OR achievement OR underrepresentation OR participation OR equity OR diversity OR inclusion OR "asset based" OR persist*)`	–**Type of search:** Advanced search (abstracts) –**Search within:** The ACM Full-Text Collection –**Publication date:** Custom Range: Jan. 2001 to Oct. 2022
IEEE Xplore	`("All Metadata":"black students" OR "All Metadata":"black people" OR "All Metadata":"black women" OR "All Metadata":"black females" OR "All Metadata":"black men" OR "All Metadata":"black males") AND ("All Metadata":"computer science" OR "All Metadata":"computer science education" OR "All Metadata":"CS" OR "All Metadata":"CS education" OR "All Metadata":"computing") AND ("All Metadata":success OR "All Metadata":achievement OR "All Metadata":underrepresentation OR "All Metadata":participation OR "All Metadata":equity OR "All Metadata":diversity OR "All Metadata":inclusion OR "All Metadata":"asset based" OR "All Metadata":persist*)`	–**Type of search:** Advanced search (metadata) –**Publication year:** Specify Year Range: 2001 to 2022 –**Search filters:** Books: disabled Conferences: enabled Journals: enabled
Engineering Village	`("black students" OR "black people" OR "black women" OR "black females" OR "black men" OR "black males") AND ("computer science" OR "computer science education" OR "CS" OR "CS education" OR "computing") AND (success OR achievement OR underrepresentation OR participation OR equity OR diversity OR inclusion OR "asset based" OR persist*)`	–**Type of search:** Quick search (abstracts) –**Date:** Published 2001 to 2022 –**Language:** English –**Autostemming:** Disabled –**Document type filters:** Conference article: enabled Journal article: enabled Conference proceeding: disabled Preprint: disabled
Scopus	`ABS ("black students" OR "black people" OR "black women" OR "black females" OR "black men" OR "black males") AND ABS ("computer science" OR "computer science education" OR "CS" OR "CS education" OR "computing") AND ABS (success OR achievement OR underrepresentation OR participation OR equity OR diversity OR inclusion OR "asset based" OR persist*)`	–**Type of search:** Advanced search (abstracts) –**Year:** 2001 to 2022 –**Document type:** "Conference Paper" and "Article" enabled. –**Publication stage:** Final –**Source type:** "Conference Proceeding" and "Journal" enabled.
EBSCOhost Web	`("black students" OR "black people" OR "black women" OR "black females" OR "black men" OR "black males") AND ("computer science" OR "computer science education" OR "CS" OR "CS education" OR "computing") AND (success OR achievement OR underrepresentation OR participation OR equity OR diversity OR inclusion OR ‘‘asset based’’ OR persist*)`	–**Type of search:** Advanced search (abstracts) –**Databases:** All databases –**Apply related words:** disabled –**Apply equivalent subjects:** disabled –**Limit your results:** "Scholarly (Peer Reviewed) Journals" enabled –**Publication date:** January 2001 to October 2022
ERIC (via ProQuest)	`ab ("black students" OR "black people" OR "black women" OR "black females" OR "black men" OR "black males") AND ab ("computer science" OR "computer science education" OR "CS" OR "CS education" OR "computing") AND ab (success OR achievement OR underrepresentation OR participation OR equity OR diversity OR inclusion OR ‘‘asset based’’ or persist*)`	–**Type of search:** Advanced search (abstracts) –**Limit to:** Peer reviewed –**Publication date:** January 2001 to October 2022
APA PsycInfo (via ProQuest)	`ab ("black students" OR "black people" OR "black women" OR "black females" OR "black men" OR "black males") AND ab ("computer science" OR "computer science education" OR "CS" OR "CS education" OR "computing") AND ab (success OR achievement OR underrepresentation OR participation OR equity OR diversity OR inclusion OR ‘‘asset based’’ OR persist*)`	–**Type of search:** Advanced search (abstracts) –**Limit to:** Peer reviewed –**Publication date:** January 2001 to October 2022

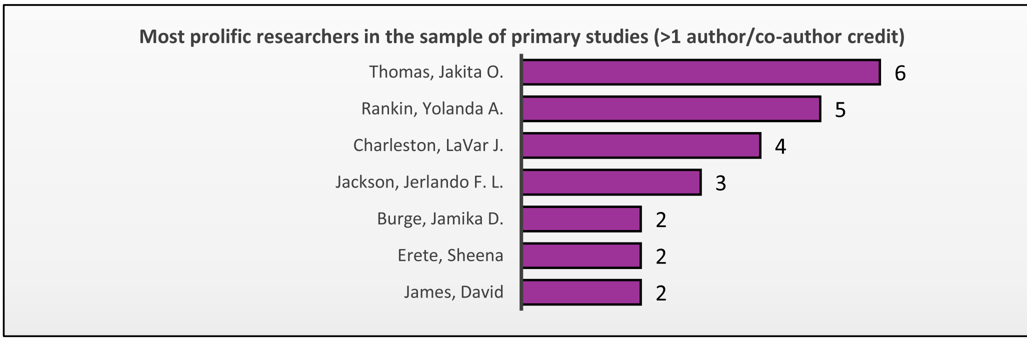

Fig. 1. A bar chart comparing the number of author/co-author credits for the researchers included in the sample of primary studies. Note that only researchers with more than one author/co-author credit are included; and, as most studies in the sample included multiple authors, the figures in this chart exceed 100% of the sample.

In order to ensure the completeness of our search results, we used snowballing and an expert-based search. First, after removing duplicate search results and applying inclusion and exclusion criteria to the remaining records, we used **Connected Papers** to snowball all eligible papers. Second, after removing duplicates from the newly imported records, and applying the inclusion and exclusion criteria to those that remained, we snowballed all eligible papers once again. Third, we repeated this snowballing process until it yielded no additional eligible papers. Finally, over the course of our search, we identified Jakita Thomas and Yolanda Rankin as experts in the persistence of Black students in undergraduate computing. Thomas and Rankin, who are credited as author or co-author of six and five papers in our sample respectively, are the most prolific researchers in our sample (see Figure 1). LaVar Charleston and Jerlando Jackson, it should be noted, were also identified as prolific researchers, having been credited as author or co-author of four and three papers in our sample, respectively. Ultimately, however, we opted not to consider Charleston or Jackson as experts for the purposes of the expert-based search because the median publication year for papers authored by them in our sample is 2013.5 and 2013, respectively. This suggests that Charleston and Jackson are no longer actively conducting research in this area and therefore cannot be considered experts for the purposes of our expert-based search. By comparison, the median publication year for Thomas's and Rankin's papers in our sample is 2020, which is also to say that they are at the forefront of asset-based scholarship involving Black students in CS education. In lieu of contacting Thomas and Rankin to ensure the completeness of our search results, however, we initially used DBLP to cross-reference our list of papers against their digital libraries. We initially made this decision not only in the interest of efficiency, reproducibility, unbiasedness, but also because we are cognizant of, and did not want to contribute further to, the burdens associated with the so-called diversity tax [69]. Since using DBLP to conduct the expert-driven search yielded not additional primary study, we therefore resolved to contact (by email) four experts and to ask them to assess the list of primary studies included in our systematic mapping study, and to propose potential additional primary studies to include in our systematic mapping study. Hence, we contacted: (1) Thomas and Rankin who are experts in the persistence of Black students in undergraduate computing; and (2) Alexander Serebrenik, and Ronnie de Souza Santos who are experts in diversity in computing (more specifically in the software engineering field). Two of these experts replied, assessed our list of primary studies, and suggested additional studies that may be relevant to our map.

2.4 Selection Process

To identify and select primary studies, we employed a three-phase, 21-round approach, as summarized by Table 4 below. When completing the selection process, we used EndNote as our reference manager.

In phase one, which consisted of three rounds, we (1) searched the selected databases using the parameters outlined in the preceding section; (2) manually screened the results for duplicate records (e.g., identical papers found in multiple databases) and ineligible paper types (e.g., book chapters); and (3) applied the inclusion-exclusion criteria to the remaining records to select relevant papers. One member of the research team (i.e., a postdoctoral fellow **[second author]**) was responsible for searching the selected databases, screening the results, applying the inclusion-exclusion criteria, and documenting their decisions at every step along the way. A second member of the research team (i.e., a faculty member **[lead author]**) was responsible for selecting a random sample of records to independently validate their inclusion or exclusion. In the event of a disagreement concerning how to classify a given paper, the research team agreed to expand the validation sample to include the remaining records, and, if needed, to use the Delphi process [70–72, 106] to resolve the disagreement. After the validation process was completed, we proceeded to phase two. Noteworthy, the Delphi process is a widely adopted iterative method that allows gathering data from experts within their domain of expertise to aggregate opinions on a given topic and reach a consensus [70, 106].

In phase two, which consisted of 12 rounds, we completed four iterations of snowballing. In the first iteration, we (4) used Connected Papers to snowball the papers (studies) selected during phase one; (5) manually screened the results for duplicate records (e.g., studies considered during phase one) and ineligible studies (e.g., studies published before 2001); and (6) applied the inclusion-exclusion criteria to the remaining records to select relevant studies. In the second iteration of this cycle, we (7) snowballed the studies selected during the previous round; (8) manually screened the results for duplicate records and ineligible studies; and (9) applied the inclusion-exclusion criteria to the remaining records to select relevant studies. The third iteration of this cycle, which included rounds 10–12, resulted in the selection of additional relevant studies. It was not until the fourth iteration of this cycle—which included rounds 13–15—that no additional relevant studies could be found. One member of the research team (i.e., a postdoctoral fellow) was responsible for snowballing the studies in our initial sample, screening the results, applying the inclusion-exclusion criteria, identifying experts in the field, and documenting their decisions along the way. In line with the validation approach used during the previous phase, a second member of the research team (i.e., a faculty member) was responsible for selecting a random sample of records examined during this phase to independently validate their inclusion or exclusion. As with the above, the research team agreed to expand the validation sample and, if needed, to use the Delphi process to resolve any potential disagreements that arose. Once the snowballing results were validated, and the research team approved the chosen experts, we proceeded to phase three.

In phase three, which consisted of six rounds, we (16) imported the digital libraries of Yolanda Rankin and Jakita Thomas. These digital libraries are online electronic libraries that can be accessed online (on Google) by typing "DBLP" followed by the name of the expert; (17) manually screened the results for duplicate records (e.g., studies considered during phase one or two) and ineligible studies (e.g., studies that are not peer reviewed); (18) applied the inclusion-exclusion criteria to the remaining records to select relevant study; (19) emailed four experts to request potential additional studies we may have missed; (20) manually screened the additional suggested studies; and (21) applied the inclusion-exclusion criteria to the remaining records to select relevant studies. One member of the research team (i.e., a postdoctoral fellow) was responsible for

Table 4. A Summary of the Three-phase, 21-round Selection Process used in this Study

Identification method	Round	Round details	Papers at start of round	Change log	Papers at end of round
Database-driven search	1	Importing into EndNote the references found in the selected databases.	**0**	–Added 132 papers.	**132**
	2	Initial screening.	**132**	–Removed 78 duplicate records.	**54**
	3	Eligibility screening using inclusion-exclusion criteria.	**54**	–Removed 37 papers not directly related to the research problem. –Removed 6 papers not containing primary research results. –Removed 1 paper taking a deficit-based approach.	**10**
Snowballing Iteration I	4	Snowballing the 10 papers identified above using connectedpapers.com	**10**	–Added 403 papers.	**413**
	5	Initial screening.	**413**	–Removed 176 duplicate records. –Removed 18 papers published before 2001.	**219**
	6	Eligibility screening using inclusion-exclusion criteria.	**219**	–Removed 176 papers not directly related to the research problem. –Removed 15 ineligible papers (e.g., book chapters, theses, not peer reviewed, etc.). –Removed 10 papers not containing primary research results. –Removed 3 papers written in a language other than English. –Removed 2 papers taking a deficit-based approach.	**13**
Snowballing Iteration II	7	Snowballing the 3 papers identified during Snowballing Iteration I.	**13**	–Added 123 papers.	**136**
	8	Initial screening.	**136**	–Removed 43 duplicate records.	**93**
	9	Eligibility screening using inclusion-exclusion criteria.	**93**	–Removed 72 papers not directly related to the research problem. –Removed 4 ineligible papers (e.g., book chapters, theses, not peer reviewed, etc.). –Removed 2 papers not containing primary research results. –Removed 1 paper written in a language other than English.	**14**
Snowballing Iteration III	10	Snowballing the 1 paper identified during Snowballing Iteration II.	**14**	–Added 41 papers.	**55**
	11	Initial screening.	**55**	–Removed 3 papers published before 2001. –Removed 2 duplicate records.	**50**
	12	Eligibility screening using inclusion-exclusion criteria.	**50**	–Removed 29 papers not directly related to the research problem. –Removed 3 ineligible papers (e.g., book chapters, theses, not peer reviewed, etc.). –Removed 2 papers not containing primary research results.	**16**
Snowballing Iteration IV	13	Snowballing the 2 papers identified during Snowballing Iteration III.	**16**	–Added 82 papers.	**98**
	14	Initial screening.	**98**	–Removed 21 duplicate records. –Removed 2 papers published before 2001.	**75**
	15	Eligibility screening using inclusion-exclusion criteria.	**75**	–Removed 57 papers not directly related to the research problem. –Removed 2 papers not containing primary research results.	**16**

(Continued)

Table 4. Continued

Identification method	Round	Round details	Papers at start of round	Change log	Papers at end of round
Expert-based search –Iteration I	16	Importing the digital libraries of Yolanda Rankin and Jakita Thomas.	**16**	–Added 88 papers.	**104**
	17	Initial screening.	**104**	–Removed 39 duplicate records.	**65**
	18	Eligibility screening using inclusion-exclusion criteria.	**65**	–Removed 38 papers not directly related to the research problem. –Removed 11 ineligible papers (e.g., book chapters, theses, not peer reviewed, etc.).	**16**
–Expert-based search –Iteration II	19	Importing the references suggested by two experts	**16**	–Added 4 papers	**20**
	20	Initial screening	**20**	–Removed 0 papers	**20**
	21	Eligibility screening using inclusion-exclusion criteria.	**20**	–Removed 4 papers not directly related to the research problem	**16**

importing records from Rankin's and Thomas's digital libraries, screening the results, applying the inclusion-exclusion criteria, and documenting their decisions along the way. Once again, a second member of the research team (i.e., a faculty member) was responsible for independently validating a random sample of records. In the event of a disagreement, the research team agreed to expand the validation sample and, if needed, use the Delphi process to reach a consensus. Once the results of the expert-driven search were validated, we proceeded to the data-collection phase of this study.

2.5 Data Collection

During the data-collection phase of this study, we completed a full-text review of all studies in the sample to identify and document (1) key study characteristics including research methods, theoretical frameworks, and research participants; (2) research findings; and (3) recommendations. To that end, one member of the research team (i.e., a postdoctoral fellow) was responsible for preparing a brief set of point-form notes for each study in the sample. This researcher was instructed by other members of the research team including the lead author (i.e., a faculty member) to capture key points for each primary study (i.e., key study characteristics, findings, and recommendations) with our research questions firmly in mind. That is, we did not attempt to create an exhaustive set of notes for each study. At the same time, if there was any doubt as to whether or not a given point was relevant, the researcher was instructed to err on the side of assuming its relevance. The researcher was also instructed to include page references with their notes to permit other members of the research team to consult the underlying study if necessary. These primary study notes would later serve as the basis for the data-analysis phase of this study.

To validate the primary study notes, (i) a meeting was held to discuss the key points for each primary study (i.e., key study characteristics, findings, and recommendations) and to suggest the investigation of some additional key points; (ii) one member of the research team (i.e., a postdoctoral fellow) then iterated over each primary studies to further extract the additional key points mentioned in the meeting; (iii) a second member of the research team (i.e., a faculty member) then independently selected a random validation sample of three primary studies, completing a full-text review of the selected studies, and validated the key points specific to each of these three primary studies. The research team agreed to address any significant discrepancies by expanding the validation sample and, if needed, using the Delphi process [70–72] to reach a consensus concerning the remaining studies.

2.6 Data Analysis

During the data-analysis phase of this study, we (i.e., the authors of this study) (1) reviewed primary study notes, tabulated study characteristics, and created master lists of findings and recommendations; (2) reconciled and consolidated tables and lists; and (3) arrayed these tables and lists into matrices to address our research questions.

First, one member (i.e., a faculty member) of the research team was responsible for independently reviewing a random sample of the primary study notes and consulting the underlying study for additional clarity where necessary.

Second, two researchers (i.e., a faculty member and a postdoctoral fellow) were then responsible for meeting to discuss tables, lists, and categories with a view towards collaboratively reconciling the potential differences spotted in them [73, 74].

Third, after finalizing the study characteristics table, thematic categories, findings, and recommendations, we arrayed the findings and recommendations into a series of matrices to address our research questions. This is useful to present data in a tabular form in accordance with the review research questions [108]. Presenting data in a tabular form is a practice that is strongly recommended when conducting systematic reviews [108]. We created three matrices to address RQ1 – that is, what factors are associated with Black students' persistence in undergraduate CS programs? The first matrix is designed to map thematic categories (column A) and their constituent persistence factors (column B) to all primary studies (the remaining columns) in our sample. The second and third matrices (i.e., Tables 8 and 9 that are available in the Appendix) map thematic categories and persistence factors to two distinct subsets of primary studies – that is, those engaging exclusively with Black women and those engaging with Black women and men. In the second and third matrices, persistence factors with no connection to the associated subset of studies were removed. In all three matrices, thematic categories are sorted in descending order based on the number of constituent persistence factors. Where two categories contained the same number of persistence factors, the category with the greater number of connections to the primary studies was placed on top. The persistence factors within each category were sorted in descending order by the number of connections to primary studies. Finally, we took the same approach to creating a matrix to address RQ2 – that is, what recommendations have been made to further bolster Black students' persistence in undergraduate CS education programs? Rather than organizing these recommendations by thematic categories, however, we opted to group them by the target audience for each recommendation.

3 RESULTS

In what follows, we (1) summarize the results of the search and selection process; (2) detail the characteristics of the primary studies in our sample; and (3) describe the results of our analysis by addressing the research questions responsible for animating this systematic mapping study.

3.1 Study Selection

Using the search and selection process outlined in the previous section, we identified a total of 16 primary studies, as summarized by Figure 2.

The database-search phase of the selection process yielded a total of 132 records. After manually excluding 78 duplicate records, we assessed the eligibility of the remaining records. Only 10 of these 54 studies satisfied the eligibility criteria. We then snowballed these 10 studies to assess

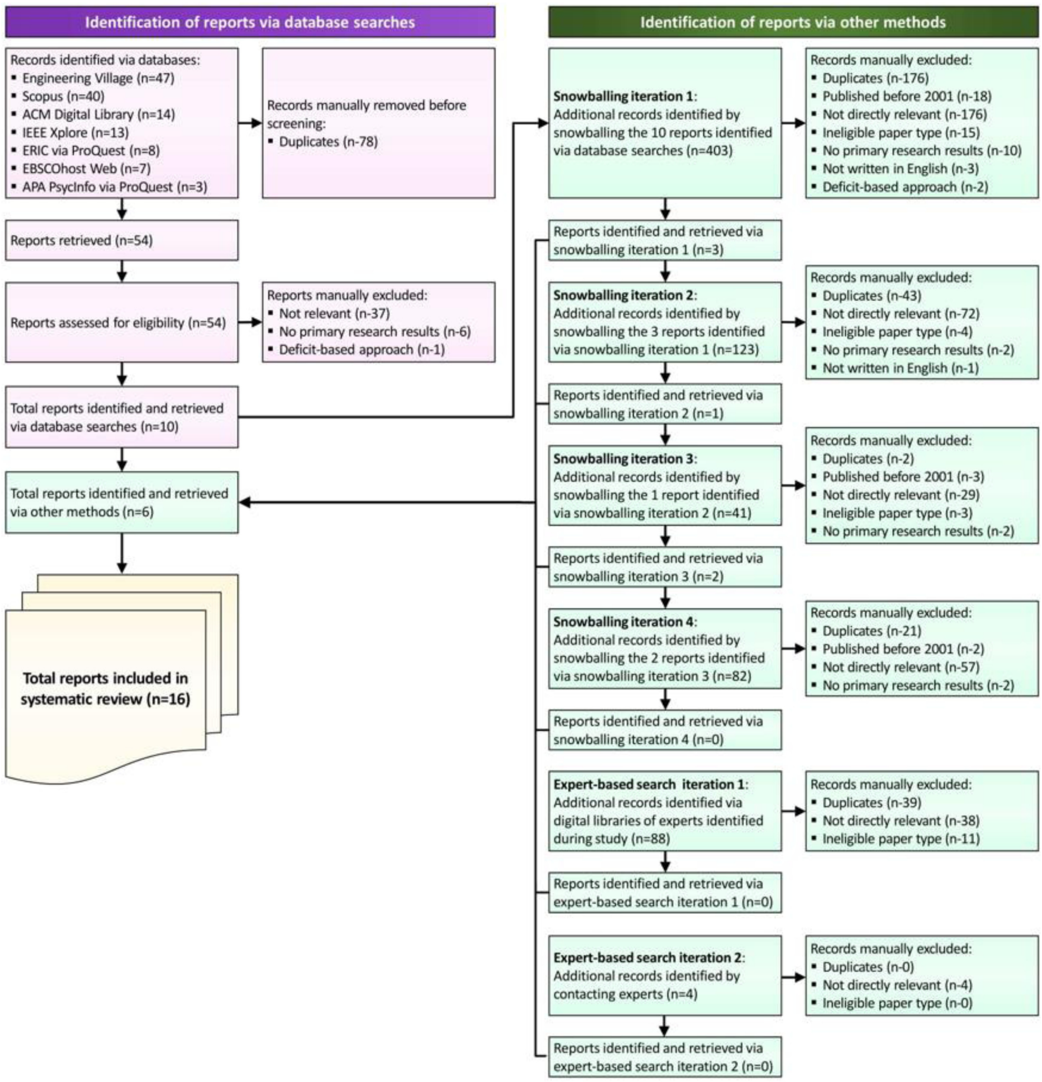

Fig. 2. A PRISMA flow diagram summarizing the results of the search and selection process.

whether any related studies met the eligibility criteria. After three iterations of this snowballing process, we added a total of 6 new studies to our sample. The fourth snowballing iteration did not result in the identification of any additional eligible studies. Accordingly, we assessed the completeness of our search and selection process by cross-referencing the digital libraries of Jakita Thomas and Yolanda Rankin against our eligibility criteria and existing sample of studies. We also contacted four experts to get potential additional studies we may have missed. Ultimately, however, the expert-based search did not result in the identification of any additional eligible studies.

3.2 Study Characteristics

Our analysis of the characteristics of the 16 primary studies which together constitute our sample (see Table 5) produced several interesting insights.

Table 5. Primary Study Characteristics

Study identifier	Partici-pants	Theories	Methods	Title	Venue
Charleston, 2012 [39]	Black students	GT	Qualitative	A Qualitative Investigation of African Americans' Decision to Pursue Computing Science Degrees: Implications for Cultivating Career Choice and Aspiration	Journal of Diversity in Higher Education
Charleston et al., 2014a [20]	Black students	CRPT	Qualitative	Using Culturally Responsive Practices to Broaden Participation in the Educational Pipeline: Addressing the Unfinished Business of Brown in the Field of Computing Sciences	The Journal of Negro Education
Charleston et al., 2014b [26]	Black women	BFT, CRF	Qualitative	Navigating Underrepresented STEM Spaces: Experiences of Black Women in U.S. Computing Science Higher Education Programs Who Actualize Success	Journal of Diversity in Higher Education
Cherry et al., 2020 [75]	Black students	None	Mixed	Exploring Computing Career Recruitment Strategies and Preferences for Black Computing Undergraduates at HBCUs	ACM Southeast Conference
Jackson et al., 2013 [76]	Black students	None	Quantitative	Changing Attitudes About Computing Science at Historically Black Colleges and Universities: Benefits of an Intervention Program Designed for Undergraduates	Journal of African American Studies
James, 2020 [77]	Black women	CRPT	Qualitative	The Use of DJing Tasks as a Pedagogical Bridge to Learning Data Structures	ACM Conference on Innovation and Technology in Computer Science Education
James & Hampton, 2020 [57]	Black women	CRPT	Qualitative	Using Black Music as a Bridge to Understanding Introductory Programming Concepts	R.E.S.P.E.C.T. Conference
Johnson et al., 2022 [78]	Black students	None	Quantitative	Students of Color Organization Improves CS1 Grades	ACM Technical Symposium on Computer Science Education
Rankin et al., 2019 [79]	Black women	None	Qualitative	Food for Thought: Supporting African American Women's Computational Algorithmic Thinking in an Intro CS Course	ACM Technical Symposium on Computer Science Education
Rankin et al., 2020 [31]	Black women	Int., BFT	Qualitative	The Role of Familial Influences in African American Women's Persistence in Computing	R.E.S.P.E.C.T. Conference
Rankin et al., 2021a [6]	Black women	Int., ST	Qualitative	Real Talk: Saturated Sites of Violence in CS Education	ACM Technical Symposium on Computer Science Education
Rankin et al., 2021b [7]	Black women	Int., ST	Qualitative	Black Women Speak: Examining Power, Privilege, and Identity in CS Education	ACM Transactions on Computing Education
Rankin & Thomas, 2020 [8]	Black women	Int.	Mixed	The Intersectional Experiences of Black Women in Computing	ACM Technical Symposium on Computer Science Education

(Continued)

Table 5. Continued

Study identifier	Partici-pants	Theories	Methods	Title	Venue
Ross et al., 2020 [50]	Black women	Int., SIT, ST	Quantitative	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
Thomas et al., 2018 [24]	Black women	Int., BFT, ST	Qualitative	Speaking Truth to Power: Exploring the Intersectional Experiences of Black Women in Computing	R.E.S.P.E.C.T. Conference
Yamaguchi & Burge, 2019 [4]	Black women	Int., GT	Mixed	Intersectionality in the Narratives of Black Women in Computing Through the Education and Workforce Pipeline	Journal for Multicultural Education

(Abbreviations: BFT = Black feminist thought; CRF = critical race feminism; CRPT = culturally relevant pedagogy theory; GT = grounded theory; int. = intersectionality; SIT = social influence theory; ST = standpoint theory).

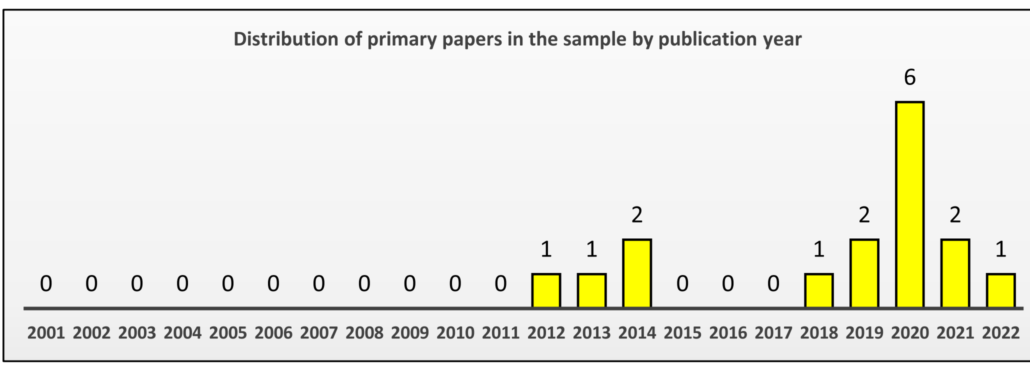

Fig. 3. A bar chart illustrating the distribution of primary studies in the sample by publication year.

First, despite designing our eligibility criteria to include studies published as distantly as the year 2001, the oldest primary study in our sample was published in 2012. More strikingly, the median publication year for the studies in our sample is 2020. Simply put, the studies in our sample are temporally skewed towards the present, as illustrated by Figure 3.

Second, though all studies in our sample focused specifically on Black people in computing, only five of 16 studies (i.e., 31.25%) focused on both Black men and women. The remaining 11 studies (i.e., 68.75%) focused specifically on Black women. In other words, none of the studies in our sample focused specifically on Black men.

Third, though four studies in our sample did not articulate a theoretical framework, the vast majority (i.e., 12/16 or 75%) did. Figure 4 provides a breakdown of the particular theories most commonly employed in our sample. Intersectionality theory was used in a total of seven studies, including qualitative, quantitative, and mixed-methods studies, and it was often used in conjunction with other theories – including, most commonly, standpoint theory followed by black feminist thought. Intersectionality theory was only used in studies focused specifically on Black women. Culturally relevant pedagogy theory was used in three primary studies but was not used in conjunction with other theories.

Fourth, 10 of 16 studies in our sample (i.e., 62.5%) employed qualitative methods. Nine of these 10 studies utilized a theoretical framework, with Rankin et al., 2019 being the sole exception. The six remaining studies were evenly split between quantitative methods (i.e., 3/16, or 18.75%) and mixed methods (i.e., 3/16, or 18.75%). Two of the three mixed-methods studies in our sample ar-

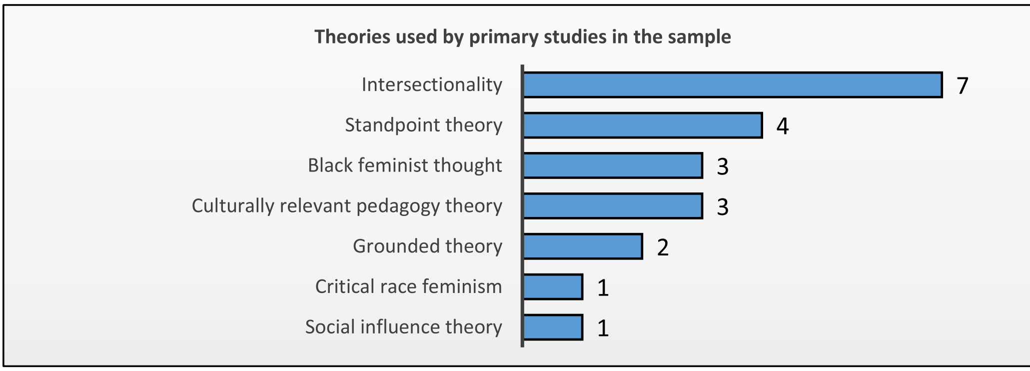

Fig. 4. A bar chart illustrating the most prevalent theories informing studies in the sample. Note that, as some studies employed multiple theories, the figures in this chart exceed 100% of the sample.

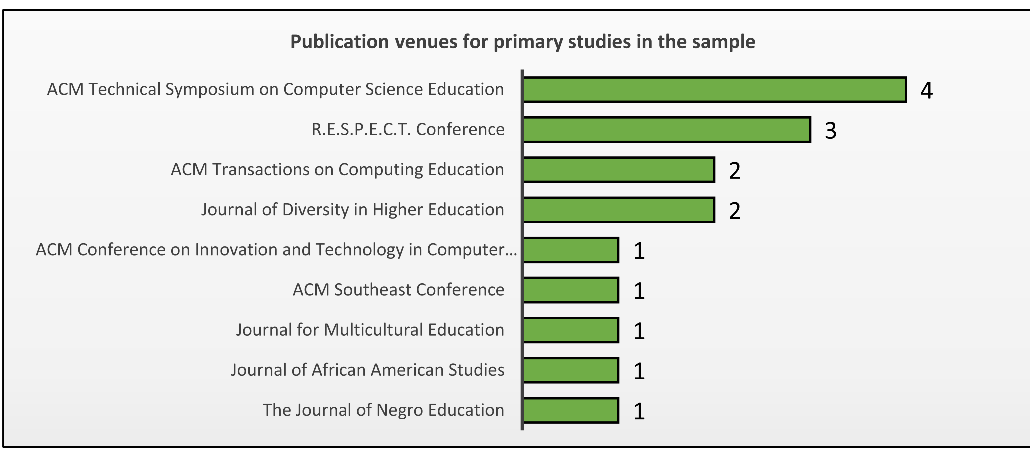

Fig. 5. A bar chart illustrating the relative distribution of publication venues for papers in the map.

ticulated a theoretical framework. Ross et al. 2020, on the other hand, was the only quantitative study to articulate a theoretical framework.

Finally, the studies in our sample were almost evenly split between conference papers (i.e., 9/16, or 56.25%) and journal articles (i.e., 7/16, or 43.75%). As illustrated by Figure 5, moreover, these papers were published in a variety of venues. Though several of these venues are explicitly geared towards equity-, diversity-, and inclusion-oriented scholarship (e.g., the Conference on Research in Equity and Sustained Participation in Engineering, Computing, and Technology, or R.E.S.P.E.C.T., and the Journal of Diversity in Higher Education), others are focused on computer science education more generally (e.g., ACM Technical Symposium on Computer Science Education and ACM Transactions on Computing Education).

3.3 Persistence Factors (RQ1)

In this section, we turn finally to our research questions, beginning with RQ1 – that is, what factors are associated with Black students' persistence in undergraduate CS programs? Based on data collected from the primary studies included in our map, we identified 13 persistence factors

Table 6. A Matrix Summarizing the Persistence Factors Identified in the Primary Studies

Persistence Factors (RQ1)		Charleston et al., 2012	Charleston et al., 2014a	Charleston et al., 2014b	Cherry et al., 2020	Jackson et al., 2013	James, 2020	James & Hampton, 2020	Johnson et al., 2022	Rankin et al., 2019	Rankin et al., 2020	Rankin et al., 2021a	Rankin et al., 2021b	Rankin & Thomas, 2020	Ross et al., 2020	Thomas et al., 2018	Yamaguchi & Burge, 2019
Social capital, networking, & support	Coping strategies or sacrifices to endure anti-Black racism in CS and associated inequities.			✓								✓	✓	✓		✓	✓
	Engagement with a Black campus club, industry-academic organization, and/or mentor network.				✓	✓			✓					✓			
	Familial cultivation, nurturing, and financial support.	✓	✓								✓					✓	
	Multi-faceted, culturally-responsive mentoring and support.	✓	✓													✓	✓
	Peer and community modeling.	✓	✓								✓			✓			
	Positive computing socialization and social interactions.	✓	✓												✓	✓	
Career & professional development	Internship and/or research lab experience.				✓												
	Leadership training.																✓
	Structured decision-making process for selecting a computing career.	✓															
Pedagogical & programmatic interventions	Culturally-responsive course content designed specifically for Black students.						✓	✓		✓							
	Targeted presentations and career fairs for Black students.				✓	✓											
Exposure & access	Early, advanced exposure to and engagement with computing.	✓									✓						
	Effective cultural and educational supports beginning in middle school.																✓

across four thematic categories, as summarized by Table 6. In what follows, we provide a brief overview of the persistence factors in each thematic category.

3.3.1 Social Capital, Networking, and Support. To endure systemic inequities and anti-Black racism in undergraduate CS programs and remain focused on their studies, Black students rely heavily on social capital, networking, and support [4, 6–8, 20, 24, 26, 75, 76, 78].

First, Black students use a range of coping strategies to persist in hostile undergraduate CS programs [4, 6–8, 24]. This is especially true at **Predominantly White Institutions (PWIs)**, where Black women are especially susceptible to experiencing isolation. For Black women attending PWIs, the ability to build social capital with students from other backgrounds is essential for persistence [8]. So too is the ability to devise and employ coping strategies, such as making an active effort to ignore the racist remarks often made by classmates [6–8]. Some Black women found that they were better able to persist by sacrificing their social lives or cultivating a singular focus on achievement [4, 26].

Second, familial cultivation, nurturing, and financial support often provides the essential groundwork for Black students' persistence [20, 24, 31, 39]. Parents often play a crucial role in initially cultivating, subsequently nurturing, and financially supporting (e.g., purchasing computers or assisting with tuition) Black students' interest in, and ability to persist in, computing [20, 39]. For Black women, family members offer important support by providing initial exposure and access to computing; engendering a sense of self-efficacy; instilling education as a family value; providing career guidance and advice; offering emotional support; and serving as role models [24, 31].

Third, Black students can derive significant benefits from involvement in Black campus clubs, industry-academic organizations, and/or mentor networks [8, 75, 76, 78]. That is, Black campus clubs or organizations create "safe havens" on campus in which Black students can establish critical networks of support [8]. More than that, involvement in a Black campus club may lead to improved grades in introductory computer science courses [78]. Along similar lines, conferences and industry-academic organizations that connect Black computing professors and professionals with Black students through networking and mentoring activities may bolster persistence in undergraduate programs and interest in pursuing graduate degrees [75, 76].

Fourth, Black students' persistence can be improved through multi-faceted, culturally-responsive mentoring and support [4, 20, 24, 39]. Many Black computing graduates credit their mentors for socializing them to the field, thereby helping them to succeed in their respective undergraduate programs [20, 39]. Some Black women have partially attributed their persistence in undergraduate CS programs to their mentors, whom they credit for actively preparing them to contend with the exclusionary culture of computing rather than sugarcoating the same [4, 24].

Fifth, peer and community modeling can bolster Black students' interest and persistence in undergraduate computing programs [8, 20, 31, 39]. Computing interactions involving a supportive community of peers can provide crucial computing socialization for Black students [20, 31, 39]. This may explain why Black women are better able to persist in **Historically Black Colleges and Universities (HBCUs)** than they are at PWIs, as they feel a stronger sense of community in the former than they do in the latter [8].

Finally, positive social interactions and computing socialization are important persistence factors for Black students in computing [20, 24, 39, 50]. These interactions occur in a variety of contexts, including through peer modeling, parental nurturing, and mentorship [24, 39]. Positive social interactions are especially impactful in conjunction with relevant cultural practices [20]. For Black women in particular, positive social interactions with computing peers have a significant effect on persistence [50].

3.3.2 Career & Professional Development. Career and professional development activities can bolster the persistence and success of Black students in undergraduate CS programs [4, 39, 75]. Black students may benefit by gaining experience in an internship, research lab, or by participating in supplemental interventions such as hack-a-thons [75]. Black women in computing professions have suggested that persistence could be improved if undergraduate CS programs placed a greater emphasis on leadership training [4]. Black students may also benefit from structured decision-making processes for converting interest in computing into a concrete plan for pursuing a computing career [39].

3.3.3 Pedagogical & Programmatic Interventions. Black students' persistence in undergraduate CS courses can be bolstered through culturally-responsive pedagogical and programmatic interventions [57, 75–77, 79]. Black women, in particular, appear to respond well to pedagogical interventions which introduce culturally-relevant course content [57, 77, 79]. Examples from the studies in our sample include a project which uses DJing and Black music to reinforce programming concepts [57, 77]; and a food-centric activity designed to support the development of **Computational Algorithmic Thinking (CAT)** capabilities [79]. Black students may also benefit from attending targeted career fairs, presentations, and mini conferences [75, 76].

3.3.4 Early Exposure & Access. Early exposure and access continue to be important predictors of Black students' persistence in computing [4, 31, 39]. That is, in addition to exposing Black students to computing early—that is, before college or university—it is important to facilitate the shift to advanced engagement and to sustain this engagement over time, as those developing an interest in computing later in life may struggle to persist in undergraduate computing programs [31, 39]. In light of the systemic inequities faced by Black students in general and Black women in particular, however, it is not enough to simply develop an early interest in computing. This interest should be supplemented with cultural and educational supports beginning as early as grade school [4].

3.4 Recommendations (RQ2)

In this section, we turn to RQ2 – that is, what recommendations have been made to further bolster Black students' persistence in undergraduate CS education programs? Based on the data collected from the primary studies in our sample, we identified 26 recommendations across six audiences or stakeholder groups, as summarized by Table 7. In what follows, we offer an overview of the recommendations for each stakeholder group.

3.4.1 Researchers. The primary studies in our sample offered a range of recommendations intended specifically for researchers. These recommendations, which provide important direction and guidance for future studies involving Black students in CS, are as follows:

(1) Rather than treating 'underrepresented minorities' or 'women of colour' as homogenous monoliths, CS education researchers should employ authentic, intentional, theoretically-informed approaches to collecting disaggregated data which illuminates the complex, intersectional experiences of, and gender-based differences among, Black students in undergraduate CS programs [6, 7, 24, 39, 50].
(2) Rather than relying exclusively on quantitative data, researchers should consciously devise qualitative and mixed-methods approaches to foregrounding Black students' perspectives on how best to reform CS education with a view towards addressing systemic inequities [6, 7, 24, 31, 75].
(3) Rankin et al., 2019 [79] call on researchers to assess the effects of culturally responsive pedagogical interventions on the computational algorithmic thinking (CAT) capabilities of a larger population of Black students.
(4) Charleston, 2012 [39] recommends examining regional and jurisdictional differences in the curricula used by, and resources available to, K-12 systems and schools for CS education.
(5) Cherry et al., 2020 [75] suggest examining in depth the relationships between motivation, interest, and work ethic for Black students in CS.

Table 7. A Matrix Summarizing the Recommendations Collected from the Primary Studies

Recommendations (RQ2)		Charleston, 2012	Charleston et al., 2014a	Charleston et al., 2014b	Cherry et al., 2020	Jackson et al., 2013	James, 2020	James & Hampton, 2020	Johnson et al., 2022	Rankin et al., 2019	Rankin et al., 2020	Rankin et al., 2021a	Rankin et al., 2021b	Rankin & Thomas, 2020	Ross et al., 2020	Thomas et al., 2018	Yamaguchi & Burge, 2019
Researchers	Collect disaggregated data to better understand complex experiences of, and gender differences among, Black students in CS programs.		✓									✓	✓		✓	✓	
	Explore Black students' perspectives on CS persistence factors.				✓						✓	✓	✓			✓	
	Assess the effects of culturally responsive pedagogical interventions on Black students' CAT capabilities.									✓							
	Examine regional differences in curricula and resources for K-12 computing education.	✓															
	Examine relationships between motivation, interest, and work ethic for Black students in CS.				✓												
	Qualitatively examine the relationship between CS grades and membership in a Black student club.								✓								
Colleges & universities	Academic administrators: improve diversity among CS faculty.	✓		✓										✓			
	CS educators: critically examine prejudices and pursue training in culturally responsive pedagogy.	✓		✓									✓				
	CS departments: establish partnerships with K-12 schools to create CS programming for Black students and their families.	✓									✓						
	CS departments: support living-learning communities, cohort-building, and communities of practice for Black students.		✓														
	PWIs: learn from HBCUs concerning how best to cultivate a more inclusive and diverse computing culture.													✓			
	PWIs: invite Black women in CS to serve as guest speakers.													✓			
	HBCUs: better support computing subfields (e.g., data science).				✓												

(Continued)

Table 7. Continued

Recommendations (RQ2)		Charleston, 2012	Charleston et al., 2014a	Charleston et al., 2014b	Cherry et al., 2020	Jackson et al., 2013	James, 2020	James & Hampton, 2020	Johnson et al., 2022	Rankin et al., 2019	Rankin et al., 2020	Rankin et al., 2021a	Rankin et al., 2021b	Rankin & Thomas, 2020	Ross et al., 2020	Thomas et al., 2018	Yamaguchi & Burge, 2019
Computing industry	Actively involve Black women in professional organizations.													✓			
	Establish partnerships with HBCUs to increase diversity.													✓			
	Establish partnerships with K-12 schools in low-income areas.	✓															
	Provide internship opportunities for Black students.	✓															
	Provide mentoring to Black students pursuing CS careers.	✓															
	Foreground perspectives of Black women to drive innovation.																✓
K-12 systems & schools	Establish partnerships with governments, computing departments, and corporations to provide Black students with computing socialization and culturally specific role models.					✓											
	Facilitate Black students' advanced engagement with computing from a young age.		✓														
	Implement more rigorous CS, math, and science courses; actively encourage Black students to enroll in those courses.	✓															
Governments	Further invest in diversity-increasing initiatives in CS.	✓															
	Invest in K-12 systems & schools that are presently under-resourced and/or lacking CS education infrastructure.	✓															
Parents	Facilitate computing socialization; encourage them to take advanced science and math courses.	✓															
	Provide positive encouragement and emotional support.	✓															

(6) Johnson et al., 2020 [78] suggest qualitatively examining the relationship between Black students' CS grades and membership in a Black campus club.

3.4.2 Colleges and Universities. The primary studies included in our map also made several recommendations for postsecondary institutions, computing departments, and CS educators. These recommendations are as follows:

(7) Academic administrators should take urgent steps to improve diversity among CS faculty at their respective institutions, with a particular emphasis on recruiting Black women for tenure-track and tenured faculty positions [8, 26, 39].
(8) CS educators should critically examine their own prejudices, pursue cultural training, and commit to developing new pedagogical approaches to supportively engaging with Black students [7, 26, 39].
(9) Computing departments should establish partnerships with K-12 systems and schools to create CS programming which engages with Black students as well as their families [31, 39].
(10) Charleston et al., 2014b [20] calls on computing departments to support the establishment of living-learning communities, cohort-building, and participation in communities of practice for Black students.
(11) Rankin & Thomas, 2020 [8] call on PWIs to learn from HBCUs concerning how best to cultivate a more inclusive and diverse computing culture for Black students.
(12) Rankin & Thomas, 2020 [8] call on PWIs to invite Black women in computing to serve as guest speakers.
(13) Cherry et al., 2020 [75] call on HBCUs to improve their offerings for computing subfields such as data science.

3.4.3 Computing Industry. Several recommendations in the primary studies were directed at a range of stakeholders in the computing industry.

(14) Rankin & Thomas, 2020 [8] call on professional organizations to actively involve Black women as members and stakeholders.
(15) Rankin & Thomas, 2020 [8] call on computing companies to establish partnerships with HBCUs to increase representation of Black students in computing.
(16) Charleston, 2012 [39] calls on leaders in the computing industry to establish partnerships with K-12 schools in low-income areas.
(17) Charleston, 2012 [39] calls on leaders in the computing industry to provide internship opportunities for Black students.
(18) Charleston, 2012 [39] calls on computing industry professionals should provide mentoring to Black students interested in pursuing CS careers.
(19) Yamaguchi & Burge, 2019 [4] call on the computing community to foreground the intersectional voices of Black women to drive innovation and productivity.

3.4.4 K-12 Systems and Schools. Charleston, 2012, Charleston et al., 2014, and Jackson et al., 2013 offered the following recommendations for K-12 systems and schools.

(20) Jackson et al., 2013 [76] call on K-12 systems and schools to establish partnerships with governments, computing departments, and corporations to provide Black students with positive computing socialization and culturally relevant computing role models.

(21) Charleston et al., 2014a [20] call on K-12 systems and schools to facilitate Black students' advanced engagement with computing from a young age.
(22) Charleston, 2012 [39] calls on K-12 systems and schools to design and implement more rigorous CS, math, and science courses; and to actively encourage Black students to enroll in those courses.

3.4.5 Governments. Charleston, 2012 offered the following recommendations for governments.

(23) Charleston, 2012 [39] calls on governments to invest in additional initiatives striving to bolster diversity in computing.
(24) Charleston, 2012 [39] calls on governments to invest in K-12 school systems that are presently under-resourced, and lacking CS infrastructure or equipment.

3.4.6 Parents. Charleston, 2012 also offered the following recommendations for the parents of Black students.

(25) Charleston, 2012 [39] suggests that parents take steps to facilitate their children's computing socialization and encourage them to take advanced science and mathematics courses.
(26) Charleston, 2012 [39] recommends that parents offer positive encouragement and emotional support to their children to aid in the development of their self-efficacy.

4 DISCUSSION

4.1 Implications for Future Research

As evidenced by the results outlined above, Black students must employ a range of persistence, coping, or survival strategies to succeed in undergraduate CS programs in spite of the ongoing experience of systemic anti-Black racism in computing contexts more generally. Though it is tempting, as Rankin et al., 2021b [7] argue, to applaud the ingenuity, determination, tenacity, and grit of these students, it would be counter-productive to do so, as this "does not address the oppressive systems that require coping mechanisms that enable Black women to **survive—but not thrive—in computing**" (p. 14, emphasis added). It is critical, in other words, that "we do not normalize the hoops that Black women jump through just to have the same opportunities as their non-Black counterparts" (p. 14). Indeed, to persist in computing, as Yamaguchi & Burge, 2019 [4] point out, some Black women develop a "singular focus on achievement", but this often comes at the cost of immense "pressure and stress" as they contend with the tremendous burden of having to represent "a whole subgroup" (p. 225). For this reason, we follow Rankin et al., 2021b [7] in arguing that "we must break down the systems that require coping and survival mechanisms" (p. 14).

The list of recommendations outlined in the preceding section offers a good starting point for this kind of systemic reform, but this list of recommendations is incomplete for several reasons. Most notably, even though non-deficit-oriented studies concerned specifically with the persistence of Black students in undergraduate CS programs have been on the rise in recent years, this research problem remains severely understudied. Indeed, despite designing our eligibility criteria to permit the inclusion of studies published as far back as 2001, the oldest study in our sample was published in 2012, and the median publication year for the studies in our sample is 2020. Moreover, there are no studies in our sample published between 2001 and 2011, or 2015 and 2017. Likewise, despite supplementing our database-driven searches with snowballing and an expert-based search, our final sample contained just 16 primary studies. It could be argued, of course, that this is reflective of a systematic mapping study that was much too narrow in its scope. In our view, however, this outcome is more accurately interpreted as a demonstration of the extent to which this research problem remains severely understudied. In order, then, to generate a more comprehensive list of recommendations for creating meaningful, systemic change for Black students in CS education, a more sustained, intentional, theoretically informed, and asset-based program of research is required.

Though London et al.'s [59] systematic mapping study ultimately reached a similar conclusion—i.e., that "there is a need for more research that is focused on the unique challenges and opportunities associated with this demographic" (p. 237)—we argue that London et al.'s broad approach obscured the true extent of this need. That is, because London et al. focused not just on Black students in undergraduate CS education, but also on marginalized students more generally in engineering and STEM education from K-12 education to graduate school and beyond, the extent of the gap thus revealed was understated. This problem is compounded by the presence of deficit-based studies in London et al.'s sample, which further understates the urgent need for additional research in this area. By accounting for these considerations, in other words, our systematic mapping study reveals the true extent of the gap to be addressed, making a distinct contribution to the literature in the process.

In line with the above, we follow Rankin et al., 2020 [31] in calling on CS education researchers to "conduct more authentic research" involving Black students in general, and Black women in particular, in computing – that is, research which "chronicles their successes and failures, the sociological factors that impact their ability to remain in the field, or in some cases, contribute[s] to them deciding to leave the field" (p. 6). Though researchers may be tempted to chase statistical representativeness by grouping Black CS students with CS students from other underrepresented backgrounds, we argue that the need for empirical specificity in this instance outweighs the usefulness of any findings derived from a representative sample of an undifferentiated mass of students. Ross et al., 2020 [50] argue, along similar lines, that researchers should "continue to expand, intentionally, into critical theory to design and analyze data" (p. 12). Though critical theoretical frameworks tend to be better suited to qualitative research methods, it is possible to employ these frameworks in quantitative and mixed-methods research as well. Indeed, Ross et al., 2020 [50] notes that intersectionality, in particular, "can be leveraged in both qualitative and quantitative research designs to seek knowledge to grow and diversify [...] CS" (p. 13). After all, Ross et al. contend, given the enormous complexity of the problem at hand, "we need many different approaches to inquiry [...] to unpack and understand the landscape of computing for those least represented in computing" (p. 13). As Slaton and Pawley [98] have argued, however, researchers' predilection for quantitative methods in general, and statistical representativeness in particular, may be responsible for obscuring our collective understanding of the experiences of 'small n' demographics in STEM fields, like Black students in undergraduate CS programs. Lucy Arellano [99] argues, more pointedly, that prevailing statistical practices in higher education research are responsible for perpetuating systemic inequities and White supremacy. In order, then, to combat persistent, systemic anti-Black racism in computing, we suggest that a greater emphasis on qualitative methods is needed in order to capture the complex experiences of Black students in undergraduate CS programs [102]. No matter the approach chosen, we believe it is imperative that CS education researchers reject deficit-oriented approaches to engaging with Black students, families, and communities in favour of one that intentionally foregrounds and privileges Black perspectives.

Additionally, the results of our map highlight the value of an intersectional approach to addressing the underrepresentation of Black students in CS education programs. Although Black students are underrepresented in CS education programs, the percentage of Black women is remarkably low. The extremely low representation of Black women brings to the fore the intersection of their identities, which interact with systems of oppression [87]. Put differently, Black women are underrepresented because they are "Black" and "women". The intersection of race and gender reinforces each other [85, 86], leading to their underrepresentation in CS education programs. Though we agree wholeheartedly with the various primary studies in our sample which emphasize the importance of attending specifically to the intersectional experiences of Black women in CS [4, 6–8, 24, 31, 50], our analysis of the characteristics of the primary studies in our sample also revealed the existence of a gap in empirical research focused specifically on the experiences of Black men in undergraduate CS programs. That is, none of the primary studies in our sample focused principally on Black men. Accordingly, we call on CS education researchers not just to conduct additional research involving Black women in CS, but also to attend to the particular systemic inequities faced by Black men in undergraduate CS programs.

4.2 Limitations

Finally, it should be noted that, despite having been carried out in accordance with a systematic methodology, our mapping study is associated with a few limitations.

First and foremost, it is doubtless that the composition of our research team shaped our approach to carrying out, and—by extension—the findings to arise from, this systematic mapping study. That is, we are an interdisciplinary team of researchers which includes computing scientists, social scientists, and experts in education. Accordingly, though we adhered to the prescribed guidelines for conducting systematic reviews [64–67], the inclusion of social scientists in our research team may impact the reproducibility of our research findings. For example, social scientists may be better attuned to identifying the features of deficit-based research. As such, our particular application of the provided eligibility criteria may differ from that of a research team with a different (inter)disciplinary composition. This is not to suggest, of course, that social scientists are better equipped to conduct this study, or vice versa. Rather, we are pointing this out to recognize the inescapable subjectivities associated with expert judgement, especially in interdisciplinary contexts. This is not the same as conceding, however, that this study is not objective, or that its findings are not valid [80, 81]. Still, to mitigate this limitation, we asked four experts in diversity in computing (education) to assess the studies included in our map and to propose potential studies our search may have missed. The feedback we received from two of them strengthened our confidence in the completeness of our study.

Second, as a result of our methodological emphasis on empirical specificity, we intentionally excluded studies which (a) lumped Black students together with students from underrepresented backgrounds more generally; (b) grouped Black students in undergraduate CS programs with Black students in other STEM fields; and (c) took a deficit-based approach to framing or addressing the underrepresentation of Blacks in computing. As a result of our decision to focus solely on studies that are concerned principally with Black students, we may have missed some important insights from studies involving not just Black students, but also students who are racialized, gendered, or minoritized more generally (e.g., [17, 38, 47]). Along similar lines, our emphasis on undergraduate CS education means that we may have missed out on insights offered by studies concerned only with Black students in graduate school (e.g., [82]) or K-12 computing education contexts (e.g., [83]). Consequently, it is possible that the persistence factors and recommendations identified in this paper are incomplete. For this reason, future mapping studies should consider taking a similar approach to identifying persistence factors and recommendations in both K-12 and graduate computing education contexts.

Furthermore, one element of our search strategy may have slightly reduced the scope of our search results. More specifically, when snowballing studies, we used Connected Papers, which only returns around 40 of the most closely related studies for each snowballed study. It is possible, therefore, that this limitation prevented us from identifying a few additional related studies. In our experience, however, relevant papers or near-misses only tended to appear in the first 10–15 studies returned by Connected Papers.

When developing the protocol that we describe in Section 2, we decided to meet and discuss our findings and opinions towards collaboratively reconciling the potential differences spotted in them. Besides, in case of significant disagreements between researchers, we also decided to use the Delphi method to reach consensus. Still, the Delphi process is not necessarily straightforward when completing a systematic mapping study. Besides, given the relatively small number of primary studies captured by our systematic mapping study, meetings proved to be the most efficient way to collaboratively reconcile the potential differences in our opinions. They therefore allowed us to reach a consensus efficiently. Nevertheless, in future work, we will explore the use of other statistical techniques (e.g., agreement indices like Cohen's Kappa, and Fleiss's Kappa [107]) to compute agreement based on inter-raters' ratings and reach a consensus faster.

Finally, as mentioned in Section 2, five members of the research team developed/revised the different versions of the protocol used in this systematic mapping study until the most optimal one was defined. Two members of the team also made several checks at each key phase of the study to ensure the protocol was properly followed throughout the completion of study. Still, one member of the research team (i.e., a postdoctoral fellow) was responsible for completing most of the search and selection process, potentially impacting the validity of the results thus generated. As noted earlier, we accounted for this threat to validity by ensuring that all decisions made throughout this process were thoroughly documented, and by tasking a second member of the research team (i.e., a faculty member) with randomly validating a sample of records included or excluded during each round and phase of the search and selection process. Though we are confident that this random validation process sufficiently addressed this validity threat, it is doubtless that this threat could have been reduced further by tasking two researchers with independently completing the search and selection process. Ultimately, however, we opted to employ the random validation process instead because we determined that the alternative would constitute an inefficient use of the limited resources available to us. We opted, instead, to direct these resources towards the data-collection process, which we associated with a higher validity threat. Indeed, despite assigning two researchers to collect and review data from the primary studies, it nevertheless remains possible that the process of collecting data from the primary studies to address the research questions was skewed by the particular researchers assigned to this task. This is, of course, an ever-present risk associated with qualitative, thematic analyses more generally, and we are confident that we adequately accounted for the associated validity threats in the design of this study.

4.3 Additional Considerations

As we stressed in Section 4.2, one of the limitations of our work is that it focuses on undergraduate CS education, which means it may have therefore missed out on insights offered by studies concerned only with Black students in graduate school or K-12 computing education contexts, among others. To mitigate these issues and further ensure the success of Black students in CS undergraduate and graduate programs, among others, we think it is crucial that future work on broadening strategies also focus on the factors specified below. This may help tackle the "Diversity crisis" that hampers the CS area [90, 95].

4.3.1 Need for More Advanced Pedagogical Approaches to Broaden the Participation in Computer Science Education. Similar to the literature (e.g., [47]), we think it is crucial to find solutions to broaden the participation of people from equity-deserving backgrounds and more particularly of Black students in CS education. It's not only about representation for college level CS education, but we should also look at how to translate that into better representation in the high paying CS jobs, which are known to have long and tough interview processes. In this context, the scarcity of CS professionals may seem artificially increased. For example, there is a saying that it is more difficult to be employed by Google than to be admitted to Harvard. This may also mean that there is more to education for success through interviews than to the knowledge gained from school. It may also mean that our pedagogical methods need to evolve to meet the CS industry needs.

This notably requires designing more advanced pedagogical approaches able to better bridge existing social disparities, tackle digital discrimination, and mend the CS digital divide that prevails among the different social groups. Similar to Bennet and Eglash [47], Ruggs and Hebl [88], as well as and Medina-Kim [21], we also think that such justice-centered pedagogical approaches should embed features such as cultural awareness, awareness of differences, and the awareness of the need for neutrality and objectivity in technology. Such approaches can also embed diverse social and cultural perspectives into curriculums, foster the development of resilience-boosting critical consciousness, enable the creation of inclusive classrooms to foster social interactions, embed traditional theoretical material, and embed creative practical material, among others. This will make CS education more appealing to all social groups and will make sure that the so-created pedagogical approaches foster social justice and technological justice. Such relevant pedagogies should be grounded in anti-racist and anti-oppressive frameworks so that all those who create the technologies we need ensure they are suitable for the diverse society and culture we live in.

The point we are emphasizing here is that these innovative pedagogical approaches, as well as programs seeking to foster the success of Black students in CS programs should engage with their intersectional experiences. This entails going beyond the intersection of identities such as race and gender to include other forms of social difference such as class, ethnicity, nationality, sexuality, religion, and geographical location (e.g., rural versus urban). Investigating how these forms of social difference intersect in CS education is important as Black male students are not homogenous, same as Black female students are quite diverse. The experience of Black students who reside in rural areas may not be the same as that of their counterparts who reside in urban areas. The experience of a Black female student from a high-income household may be different from their low-income counterpart. Similarly, the experience of a Black female student who is a Muslim would be different from that of a non-Muslim Black female student.

To be able to better enforce such pedagogical approaches, professors should also receive professional development under the form of an EDI training emphasizing cultural diversity as well as sensitivity [88] toward equity-deserving groups.

Such pedagogical approaches will drive the academic training of CS professionals who are better aware of the socio-cultural specificities of their society as well as working environment and are better equipped to address them in their technical work. Hence, when recruiting and promoting in the CS industry, the so-trained CS professionals will make sure that they also give a fair shot to employees and leaders coming from equity-deserving backgrounds. Besides, when developing intelligent systems for instance, these CS professionals will be well-equipped to make them EDI-aware by notably making them able to better capture and fairly process socio-cultural expressions, to efficiently capture and manage socio-cultural conflicts, and so on. This will enable a better expression of empathy, mitigate stereotypical behaviors, mitigate prejudices, and the like. This could lead to the creation of more robust discrimination-aware intelligent systems that are able to properly tackle digital discrimination. This will help reduce social inequities by mitigating the consequential and sometimes unfair decisions that may be made by such systems and which may have an adverse impact on credit scores, insurance payouts, and even health evaluations, just to name a few [89]. Adams and Khomh [90], as well as Ferrer et al. [94] discuss more extensively the digital discrimination that intelligent agents or other AI-based systems may engender when making automated decisions based on specific individual attributes (e.g., income, education, gender, and ethnicity) or when relying on biased data engineering practices.

4.3.2 Need to Advocate for More EDI Alternative Metrics and to Raise Awareness Regarding the Achievements of Black People in Computer Science. Numerous talented researchers coming from underrepresented groups, and especially Black researchers may be left out of the CS historical recounting or may not be sufficiently cited because their names may sound too "exotic". Usually, their scientific work is not sufficiently acknowledged because of their cultural background that may give the impression that their work is not trustworthy enough. To mitigate such concerns, existing classification schemes used to rank universities and/or researchers worldwide should be more inclusive to allow racialized researchers to be more promoted, cited and represented based on the use of alternative criteria and/or metrics when classifying researchers. Such classification schemes should also rely on criteria that are more inclusive and that embody different ways to assess the quality of the research and/or its excellence. Besides, scientific databases that are extensively used by researchers to find CS scholarly studies should also find ways to be more inclusive. This will help increase the visibility of racialized researchers and foster the vulgarization of their work.

Several scientists from underrepresented groups and more particularly the Black community have also contributed to the emergence of CS. However, their achievements are sometimes overlooked by the scientific community or downplayed by society in general. There is therefore a need to find ways to vulgarize the impact that minoritized groups and more specifically Black people have had on CS progress. This calls for the promotion of the tools they have created and the patents they have obtained, on the acknowledgement of their impact on CS research, and so on. This also calls for the organization of more seminars to raise cultural awareness in CS research, for the need to educate more on race issues and to better promote diversity in colleges and universities CS programs [88].

This will make sure that existing researchers coming from minoritized groups become as famous as they need to be and are seen as successful role models by the future generations, and more particularly by younger prospective researchers coming from minoritized groups. This will make sure that the future researchers coming from minoritized groups have enough confidence in their ability to become renowned scientists and to see their scientific contributions being better acknowledged by the scientific community and by the society in general. This is in accordance with studies that concluded for instance that female students who have witnessed/interacted with successful expert women (e.g., advanced peers, professionals, or professors) who specialized in STEM have been able to achieve higher performance than the ones who were not exposed to such role models [88].

4.3.3 Need to Advocate for Double-Blind Review and/or EDI in the Scientific Papers Reporting and Review Processes. Researchers coming from minoritized groups and more particularly Black researchers are usually less cited than other researchers coming from dominating groups. This may be due to unconscious (unintentional) racially and ethnically biased citations patterns among others [92, 93]. These citation patterns that also impact authors from some geographical regions [89] may have an adverse impact on authors belonging to some racial and ethnic groups. More specifically, as Bertolero et al. [93] point out, such citation patterns are tangible examples of biases against racialized and minoritized people, which usually translate to significant disparities in promotion, retention, grant funding, awards, collaborative opportunities, and publications. These citation patterns therefore result in a slow career advancement, and relatively low scientific prestige. These citations patterns may discourage Black students to enter graduate schools because they may think it could be very challenging or even impossible for them to thrive in the CS field as researchers. To mitigate that adverse impact, guidelines for authors proposed by journals should encourage authors to also mention in their manuscripts, when applicable, the relevant papers published by authors from equity-deserving backgrounds (e.g., Black authors, authors from developing countries). This is in accordance with Ray et al. [92] who recommend including a Citation Diversity Statement in a manuscript to mitigate racially and ethnically citation patterns. The rationale is that such a statement can foster EDI by addressing the extent to which the authors of a manuscript have included relevant literature that accurately represents the intellectual and social diversity within their field and taken into consideration the impact of their research practices on members of equity-seeking groups. Ray et al. [92] further explain how to support the implementation of Citation Diversity Statements using computer algorithms that can leverage diversity considerations such as race, ethnicity, or nationality (e.g., country of origin).

Noteworthy, unconscious racially biased citations patterns may also hinder the publication in some journal tiers of the manuscripts written by Black researchers among others [93]. These patterns may particularly be detrimental to Black researchers who usually struggle a lot to have their papers accepted in some prestigious conferences and journals, especially when they are lead authors. For instance, some journal editors may be reluctant to publish manuscripts submitted by researchers coming from some racial and ethnic groups (e.g., Black researchers, researchers from developing countries) since publications from these researchers are not expected to attract as many readers as the publications of other researchers from dominant groups. Hence, publications of researchers coming from some racialized and minoritized groups are sometimes expected to yield fewer citations due to racially and ethnically biased citations patterns and to result in a decrease of the prestige (e.g., impact factors, citation scores) of journals publishing them. There is therefore a need for more systematic double-blind reviews to make paper review processes anonymous and as such, increase the chances of acceptance of papers published by Black researchers in CS. In case there is no double-blind peer review and/or anonymization process, there is also a need to recommend an EDI training to all reviewers before allowing them to review a journal paper or a workshop/conference paper. This will foster fairness in the review process.

It is important to note here that we are not finger-pointing at journal editors and journal reviewers especially since they are making huge efforts to make sure the CS research landscape remains flourishing. We are just trying to notably raise awareness regarding the need for them to encourage authors to further acknowledge the contributions made by equity-deserving groups (e.g., Black researchers) to the CS research landscape.

5 OTHER INFORMATION

5.1 Protocol

As stated earlier, several members of the research team developed/revised the different versions of the protocol used in this systematic mapping study until the most optimal one was defined. In the initial version of the protocol, the search strategy consisted in relying on (1) four databases to complete the database-driven search; and (2) the manual search to identify additional primary studies that were missed when completing the database-driven search. After the first round of revisions made by the reviewers on our first manuscript submitted in March 2022 to the ACM TOCE journal and the concerns these reviewers raised regarding some strategies used to conduct our study, we decided to amend the protocol accordingly. As explained in Section 2, our protocol now involves searching candidate studies based on three search techniques: database-driven search, snowballing, and expert-based search. Besides, our database-driven search now relies on seven databases. These databases respectively belong to the fields of computing, engineering, science, psychology, and education or social sciences. We used the revised protocol to redo our study from the beginning and to report the so-obtained study.

6 CONCLUSION

Today, Black students continue to experience systemic anti-Black racism in undergraduate computer science (CS) programs, compromising their ability to persist and thrive in CS programs and professions. Black women, in particular, experience CS programs as saturated sites of violence [7] and have negative experiences when evolving in the CS area [89]. Despite the specificity of these experiences, researchers often lump Black students in CS programs together with Black students in related STEM fields, or with students from underrepresented backgrounds more generally. Consequently, no previous systematic reviews have focused specifically on non-deficit-oriented approaches to bolstering the persistence of Black students in undergraduate CS programs. This systematic mapping study addressed this gap by illuminating the current state of the extant literature and identifying avenues for further study.

In carrying out this study, we identified a total of 16 empirical studies, including qualitative, quantitative, and mixed-methods studies informed by a range of theoretical frameworks. Considered together, these studies reveal that Black students leverage various forms of social capital and employ a range of persistence, coping, or survival strategies to succeed in undergraduate CS programs despite the ongoing experience of systemic anti-Black racism. Crucially, however, these persistence strategies only permit Black students to persist, but not thrive, in undergraduate CS programs. Accordingly, we contend that more needs to be done to address the systemic inequities faced by Black people in general, and Black women in particular, in computing programs and professions. As evidenced by the small number of primary studies captured by this systematic mapping study, there exists an urgent need for additional, asset-based empirical studies involving Black students in CS. In addition to foregrounding the intersectional experiences of Black women in CS, future studies should attend to the currently understudied experiences of Black men.

CS education is not, as Yolanda Rankin, Jakita Thomas, and Sheena Erete [6] point out, a colour-evasive meritocracy, but a "matrix of intersecting oppressions" (p. 6). In order, then, to address the systemic inequities faced by Black students in undergraduate CS education, researchers must "expose how interlocking systems of power enable oppression in the field" (p. 6). Accordingly, we follow Rankin, Thomas, and Erete by calling on CS researchers and educators to reject deficit-oriented approaches to engaging with Black students, families, and communities in favour of one that intentionally foregrounds and privileges Black perspectives. This is the first step towards moving from "What do Black students need to survive in CS?" to "What do Black students need to thrive in CS?".

COMPETING INTERESTS

No member of the research team has disclosed any potential conflicts of interest, whether real or perceived, in relation to the subject of this study.

APPENDIX

Table 8. A Matrix Summarizing the Persistence Factors Identified in the Primary Studies Focused Specifically on Black Women

Persistence Factors (RQ1) Primary Studies Focused on Black Women		Charleston et al., 2014b	James, 2020	James & Hampton, 2020	Rankin et al., 2019	Rankin et al., 2020	Rankin et al., 2021a	Rankin et al., 2021b	Rankin & Thomas, 2020	Ross et al., 2020	Thomas et al., 2018	Yamaguchi & Burge, 2019
Social capital, networking, & support	Coping strategies or sacrifices to endure anti-Black racism in CS and associated inequities.	✓					✓	✓	✓		✓	✓
	Engagement with a Black campus club, industry-academic organization, and/or mentor network.								✓			
	Familial cultivation, nurturing, and financial support.					✓					✓	
	Multi-faceted, culturally responsive mentoring and support.										✓	✓
	Peer and community modeling.					✓			✓			
	Positive computing socialization and social interactions.									✓	✓	
Exposure & access	Early, advanced exposure to and engagement with computing.					✓						
	Effective cultural and educational supports beginning in middle school.											✓
Pedagogical & programmatic interventions	Culturally responsive course content designed specifically for Black students.		✓	✓	✓							
Career & professional development	Leadership training.											✓

Table 9. A Matrix Summarizing the Persistence Factors Identified in the Primary Studies Focused on Both Black Men and Women

Persistence Factors (RQ1) Primary Studies Focused on Black Men & Women		Charleston et al., 2012	Charleston et al., 2014a	Cherry et al., 2020	Jackson et al., 2013	Johnson et al., 2022
Social capital, networking, & support	Engagement with a Black campus club, industry-academic organization, and/or mentor network.			✓	✓	✓
	Familial cultivation, nurturing, and financial support.	✓	✓			
	Multi-faceted, culturally responsive mentoring and support.	✓	✓			
	Peer and community modeling.	✓	✓			
	Positive computing socialization and social interactions.	✓	✓			
Career & professional development	Internship and/or research lab experience.			✓		
	Structured decision-making process for selecting a computing career.	✓				
Pedagogical & programmatic interventions	Targeted presentations and career fairs for Black students.			✓	✓	
Exposure & access	Early, advanced exposure to and engagement with computing.	✓				

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