

RESEARCH REVIEW

Research literature on women of color in undergraduate engineering education: A systematic thematic synthesis

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Abstract

Background: To address social disparities and generate an innovative workforce, engineering higher education should provide learning environments that benefit students from all backgrounds. However, because engineering programs are not enrolling or retaining women of color at demographic parity, a better understanding of these students' experiences is needed to develop effective interventions.

Purpose: This study analyzes research on women of color in undergraduate engineering education to determine what influences their experiences, participation, and advancement. We identify challenges to and strategies for persistence and present recommendations for engineering institutions to create interventions that support women of color and mitigate institutional inequities.

Scope/Method: Using the snowballing method, we identified 65 empirical studies published between 1999 and 2015 that met the criteria for this review. These studies represented qualitative, mixed-methods, and quantitative methodologies from various fields. We conducted a systematic thematic synthesis, informed by frames of intersectionality, critical race theory, and community cultural wealth.

Conclusions: Women of color use navigational strategies to address the social pain of race and gender inequity in engineering education. Institutions should take responsibility for generating a sense of belonging for women of color and provide social and structural supports that increase self-efficacy, address social pain, and improve retention.

KEYWORDS

inclusivity, retention, systematic synthesis, undergraduate, women of color

1 | INTRODUCTION

The need to improve avenues for women of color (WOC) to succeed in engineering in the United States has been well established. As national demographics shift, educational institutions have both the obligation and the motivation to

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develop learning environments that benefit students of all backgrounds, including those from marginalized groups, in the service of correcting social disparities and generating a diverse and innovative workforce. Yet, engineering education programs have not been successful in enrolling and retaining WOC—women identifying as Asian or Asian American, Black or African American, Hispanic or Latina/Latinx, Native American (American Indian or Alaska Native), Native Hawaiian or Other Pacific Islander, or mixed race/ethnicity, by these or other appellations (Ong, Wright, Espinosa, & Orfield, 2011)—at levels at least at demographic parity. In 2017, WOC (ages 18–24) represented approximately 20.6% of the U.S. population (National Science Foundation, National Center for Science and Engineering Statistics, 2019). However, according to the most recent data reported by the National Science Foundation (from 2016), only 7.6% of engineering undergraduate degrees were awarded to WOC compared to 12.7% awarded to White women and 79.1% awarded to men of any race/ethnicity (NSF/NCSES, 2019).

With more diversity in engineering, including WOC, the United States could avert an impending engineering talent shortage (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2011) and improve creative and competitive problem solving (Varassi, 2012; Wulf, 2002). Working now to help undergraduate WOC succeed in engineering programs removes barriers to success for diverse populations (Lord et al., 2009), generates engineering role models for today's increasingly diverse youth (Hess, Gault, & Yi, 2013), and supports the future diversity of the field (Hess et al., 2013; Kachchaf, Ko, Hodari, & Ong, 2015; Nelson & Brammer, 2010; Nelson & Rogers, 2003). To achieve levels of participation that reflect U.S. demographics and to benefit from the engineering innovation that can be generated by diversity (Frehill, DiFabio & Hill, 2008), we must better understand the lived experiences of WOC in undergraduate engineering programs and develop solutions grounded in known factors that help or hinder their success.

This article describes a subset of findings from a multiyear project examining the factors that affect the experiences, participation, and advancement of women of color in engineering (WOCE) higher education and careers. In the project, we examined and synthesized quantitative, qualitative, and mixed methods empirical studies published between January 1999 and March 2015 when the project closed its literature searches. The project spanned multiple disciplines (e.g., education, psychology, sociology, and science studies); adopted an intersectional lens; and utilized snowballing, a systematic, rigorous data collection method (Jaumot-Pascual, Ko, Ong, & Hodari, 2016). For the purposes of this article and due to the limited findings of literature on graduate students, faculty, and other professionals, we focused on results about WOCE in their undergraduate education. We conducted a systematic thematic synthesis (Booth et al., 2016; Thomas & Harden, 2008), which compiles a comprehensive set of research on a phenomenon and uses thematic analysis to identify key themes across the research that expand theoretical understanding of the literature as a whole. Similar to Martin and colleagues' approach, our analysis allowed for inclusion of a variety of types of studies and the identification of "productive directions for future research and practice" (Martin et al., 2018, p. 3).

We adopted the intertwining theoretical frameworks of critical race theory (CRT; Bell, 1995; Delgado & Stefancic, 2012) and intersectionality (Crenshaw, 1991, 1993) to examine the complexities experienced at the intersection of gender and race/ethnicity that may contribute to WOC's underrepresentation in engineering higher education, which, as part of the U.S. education system, historically advantages White males (Thelin, 2011). We intentionally brought social justice and intersectional lenses to this analysis, with an awareness that solving the nation's engineering knowledge and labor gaps is the responsibility of institutions, not of marginalized groups. This study follows the work of other researchers who have advocated for an asset-based view of marginalized students (Martin et al., 2018; Samuelson & Litzler, 2016; Yosso, 2005) over deficit models that seek to "fix" students rather than to fix systems and institutions (Valencia, 2010). Yosso's (2005) community cultural wealth (CCW) theory in particular provides helpful theoretical background for understanding asset-based factors in student life.

Few other literature syntheses have addressed engineering education from within an intersectional framework, with two notable exceptions. One, a synthesis of empirical literature on WOC in science, technology, engineering, and mathematics (STEM) education programs and careers led by Ong et al. (2011), discredited the notion that WOC were not interested in or academically capable of succeeding in STEM education and careers. It offered alternative explanations for attrition and persistence that included types of learning environments, self-efficacy, funding, and supportive networks. While this synthesis included engineering, it did not disaggregate or report findings by discipline, and, as a result, focused on STEM higher education in general. The other is a white paper by Fletcher et al. (2017), commissioned by the National Society of Black Engineers (NSBE) and other organizations, which summarized literature specifically about African American women students and professionals in engineering and science fields and detailed the challenges they face, such as tokenism, isolation, extra scrutiny by peers, and pay inequities. This paper emphasized African American women's intersectionality, or embodiment of two pervasive prejudices, sexism and racism, in the United

States and particularly in STEM. Similar to the synthesis by Ong et al. (2011), however, the literature summary of this white paper did not focus solely on engineering.

Thus, our study is unique in its focus specifically on WOCE in their undergraduate education. It synthesizes a 15-year period of empirical research on their experiences, persistence factors, interventions, challenges, and outcomes in engineering programs and presents recommendations for institutions, faculty, and researchers, constituting an original contribution to the literature on solutions for advancing WOCE.

2 | THEORETICAL FRAMEWORK

This study utilized the interrelated theoretical frames of CRT, intersectionality, and CCW. Developed from the discipline of legal studies, CRT is a theory that examines phenomena in U.S. society and culture by applying critical analysis of race, law, and power to expose how racism exists at an institutional level (such as in educational institutions) to privilege members of the dominant White culture to the exclusion of people of color (Bell, 1995; Solórzano, 1997; Solórzano, Ceja, & Yosso, 2000). Intersectionality theory acknowledges that multiple oppressions—such as racism, sexism, homophobia, or ableism—intersect in the lived experiences of people of color. Here, we applied the views of Crenshaw (1991; see also Crenshaw, 1993, 2015), who advanced the understanding of intersectionality for WOC by critiquing feminist and antiracist practices that “expound identity as woman or person of color as an either/or proposition” (p. 1242). Crenshaw, as well as others (Collins, 2000; Collins & Bilge, 2016; Delgado & Stefancic, 2012), has called for the recognition of interlocking gendered and raced oppressions (among other oppressions) and for clear articulation of how social inequalities are compounded for those who embody multiple marginalized identities. In the context of engineering education, ignoring intersectionality can lead to a lack of understanding or overgeneralization about the experiences of WOC (Pawley, 2013, 2019). As Leonard, Atwaters, Leggon, Pearson, and Gaines (2013) explain,

Many studies tend to frame the issues of underrepresentation in engineering in terms of race/ethnicity OR gender. Few studies focus on underrepresented racial/ethnic minority students, fewer disaggregate by race and ethnicity ... and fewer still disaggregate race/ethnicity by gender. ... The results of the confluence of race, ethnicity and gender are greater than the sum of the statuses. Gender is inextricably intertwined with race and ethnicity: race/ethnicity impacts how one experiences being male or female, and gender impacts how one experiences belonging to a particular race and/or ethnic group. (p. 86).

Furthermore, scholars and practitioners in STEM education (Leyva, Massa, & Battey, 2016) increasingly recognize that intervention strategies that address one aspect of cultural identity, such as support programs targeted to either people of color or women, have limited effectiveness for students who embody multiple marginalities. Some researchers (Foor, Walden, & Trytten, 2007) have suggested that intersectionality is a more productive approach for promoting theoretical advances and practical solutions.

The CCW framework (Villalpando & Solórzano, 2005; Yosso, 2005, 2006; Yosso, Smith, Ceja, & Solórzano, 2009), which grew out of CRT, acknowledges the cultural wealth that stems from the lived experiences of marginalized students. Employing an asset-based perspective rather than a deficit model, this framework encompasses six forms of capital that students bring with them into educational spaces. Aspirational capital refers to abilities to “maintain hopes and dreams for the future, even in the face of real and perceived barriers” (Yosso, 2005, p. 77). Linguistic capital reflects the “intellectual and social skills attained through communication experiences” in their homes that enable students of color to engage at school in multiple languages and use a wide range of communication skills (p. 77). Familial capital refers to support from family members who share “those cultural knowledges ... that carry a sense of community history, memory, and cultural intuition” (p. 79). Yosso conceptualized a broad meaning of “family” to include extended kin and friends, stating that such ties minimize isolation and provide connections to community and resources. Social capital reflects “networks of people and community resources,” including peers and others who provide emotional support (p. 80). Navigational capital refers to skills and resources to “maneuver through structures of inequality permeated by racism” such as predominantly White educational institutions (p. 80). Finally, resistant capital refers to “knowledges and skills fostered through oppositional behavior” that often lead to behaviors and attitudes that “challenge the status quo” (p. 81; see also Solórzano & Villalpando, 1998). The CCW framework counterposes the types of cultural capital (e.g., financial, social ties, class, and education qualifiers) that are traditionally valued in White, dominant-culture institutions and broadens the definition of which cultural assets should be valued and recognized in education settings.

While there is a growing number of research studies that use the CCW framework to explore entry and persistence in higher education (Brooms & Davis, 2017; Holland, 2017; Huber, 2009; Pérez, 2017), very few focus on STEM (Denton, Borrego, & Boklage, 2020) or engineering. One notable exception is by Samuelson and Litzler (2016), who conducted secondary analysis on interviews with 31 African American and Latino/a undergraduates in engineering education. In addition to finding that cultural wealth took different forms—for example, navigating engineering programs, being motivated by social justice—the researchers noted that students referenced more than one type of capital, suggesting that the varieties of capital were dynamic in how they interacted with one another. Samuelson and Litzler (2016) disaggregated their data by gender, so they were able to capture some data specific to WOCE, but the researchers called for more research to be conducted on this demographic.

The interconnected frameworks of CRT, intersectionality, and CCW are useful for understanding phenomena experienced by WOCE as well as their asset-based strategies for persistence in their undergraduate education. We have selected these frameworks to reflect our commitment to use this study to address the social barriers that WOCE face in their undergraduate programs and to locate the responsibility for improving their outcomes within institutions of higher education, not within marginalized communities.

3 | METHODS

Based on Booth et al.'s (2016) classification of synthesis methods, our study is consistent with a systematic thematic synthesis, which (a) seeks to integrate and interpret a comprehensive set of research on a phenomenon, independently of its epistemology or methodology, allowing for the integration of qualitative, quantitative, and mixed methods studies; (b) uses the elements of thematic analysis to approach the data; and (c) has the goal of generating “new interpretive constructs, explanations or hypotheses” (Thomas & Harden, 2008, p. 1). In our synthesis, we implemented the interpretive construct of social pain (Eisenberger & Lieberman, 2005) as an umbrella term for phenomena caused by social exclusion and rejection that are separately present in the engineering education literature, such as sexual harassment or isolation. Our synthesis also aims to identify implications for practice and policy as well as opportunities for further research around the factors that influence WOC's persistence in engineering education (Borrego, Foster, & Froyd, 2014).

We followed Thomas and Harden's (2008) methods for conducting thematic syntheses and adapted elements from Lauer et al. (2005), such as the steps in a research synthesis. We also followed Borrego, Foster, and Froyd's (2015) (see also Martin et al., 2018) recommendations for conducting systematic reviews, including having a uniform set of criteria, having an interdisciplinary team, and making our methods explicit. For the crucial stage of literature search and selection, we chose the snowballing method, based on Wohlin's (2014) work, for its efficiency, comprehensiveness, and systematic nature.

Snowballing requires first identifying and then searching using combinations of search terms to generate an initial set of literature (the start set) that meets the study's criteria and can be synthesized. Forward and backward snowballing is then conducted on the works in the start set. Backward snowballing reviews the bibliography of each study in the start set and assesses the literature referenced there for additions to the synthesis. Forward snowballing identifies any literature that has cited the pieces in the start set and assesses those for inclusion as well. Each study added from forward or backward snowballing expands the body of literature for synthesis.

With past syntheses, our team had encountered a number of challenges and inefficiencies in the search and selection processes. With this in mind, we modified our strategy (detailed below) for this study by increasing the number of search terms to cast a broader net; selecting and testing several search engines before choosing one to capture a high-quality start set; and relying on the snowballing method to develop the final literature set. These changes reduced our number of returned empty searches and duplicate results, eliminated the need for inefficient literature solicitation, and allowed us to capture a comprehensive literature set, while effectively and efficiently investing our time and resources.

3.1 | Stage 1: Pre-search activities

Wohlin (2014) does not lay out a method for establishing an optimal start set on which to conduct the snowballing process. We, therefore, formulated our own pre-search steps to improve efficiency of our searches and ensure that the results met our standards of relevance and quality. Pre-search activities included establishing search, selection, and

quality appraisal filtering criteria; selecting a search engine; generating a list of more than 1,000 search terms; and building search strings that would return the most relevant results from our chosen search engine, Google Scholar (GS).

3.1.1 | Establishing the search, selection, and quality appraisal filtering criteria

We defined three sets of criteria: one to guide the literature search, one to guide literature selection, and one to appraise the quality of the studies. The search criteria were chosen to ensure that literature returned by our searches adhered to the study's time frame (publication from January 1999 to March 2015 when our literature searches stopped) and three content areas of interest (engineering, gender, and race/ethnicity, grouped as intersectionality). The selection criteria guided which pieces returned by the searches qualified for inclusion in the synthesis, for example, those which reported on national data, had been published, or served as "gray literature." Gray literature is literature that is unpublished or is published in noncommercial form, including conference proceedings and dissertations. These types of literature, which are usually excluded from systematic reviews, can be of high quality and reflect up-to-date research on certain topics (Mahood, Van Eerd, & Irvin, 2014). Indeed, we found that 42.0% of our collection comprised gray literature that had been released between January 2009 and March 2015. We applied the quality appraisal filtering criteria seen in Table 1 to ensure that all studies, including the gray literature, met our standard for empirical research. These criteria were used to filter the literature found in the establishment of the start set and in the snowballing process.

3.1.2 | Creating a list of search terms

We identified three essential categories of search terms, engineering, gender, and race/ethnicity, directly related to our research question, "What are the factors that keep women of color in engineering disciplines?" We employed several strategies to make the list of terms both thorough and precise, for example, selecting only those terms that were most pertinent to those categories (i.e., engineering, not engineering and computer science or other STEM disciplines); using both commonly and less commonly used terms (e.g., underrepresented and nondominant); and using both current and

TABLE 1 Search, selection, and quality appraisal filtering criteria applied to literature for inclusion in the synthesis

Type	Category	Definition
Search and selection	Intersectionality (race/ethnicity and gender)	Report findings addressing intersectionality of women of color; provide findings specific for this population and/or disaggregate data by both race/ethnicity and gender
Search and selection	Engineering	Report findings specifically on engineering, not STEM as a whole nor a combination of fields that included engineering
Search and selection	Publication date	Published or made accessible to the public between January 1999 and March 2015 ^a
Selection	Higher education and/or professionals	Report findings on students in higher education (undergraduate and graduate students; excluding K-12 education) and professionals (including faculty)
Selection	National data	Report on national United States students, employees, schools, institutions of higher education, and employment systems ^b
Selection	Types of documents	Published (journal articles or books) or gray literature (conference proceedings or papers, dissertations, or reports); or sections within larger works (e.g., book chapters)
Quality appraisal	Empirical research	Report empirical research, defined as presenting a research question, research design, data collection (including from pre-existing data) and analysis methods (including secondary analysis), findings, and answers to the research question ^c

^aMarch 2015 was the project's end date for literature searches. Coding of the literature commenced after March 2015.

^bIf this information was not available and nothing else (such as the author's institutional affiliation) suggested the report involved foreign nationals, we assumed that study participants were from the United States.

^cFollowing the recommendation of several authors (Borrego, Foster, & Froyd, 2014, 2015; Heyvaert et al., 2017; Walsh & Downe, 2006), our team appraised the quality of studies to ensure they fulfilled this definition. Studies that did not minimally fulfill these criteria were not included in the synthesis.

obsolete terms (e.g., Black, African American, Afro American, and Negro). Guided by the three essential categories, we compiled an exhaustive list of more than 1,000 terms, with the majority of the words affiliated with race/ethnicity terms, specifically countries and tribes. These terms were then used to create search strings. Here are some sample terms we chose for each category and for the intersection of gender and race/ethnicity:

Engineering: engineer, engineering.

Gender: women, female, gender.

Race/ethnicity: race, ethnicity, Hispanic, Spanish, Latina, Chicana.

Intersection of gender and race/ethnicity: women of color, minority women.

3.1.3 | Selecting the search engine

As discussed previously, we went into the search process with an intention to gather a comprehensive literature set while being time-efficient and limiting redundancies and empty searches. We compared GS, the engine recommended by Wohlin (2014), to many other engines and directories, including Engineering Village, ERIC, and open source dissertation directories such as oad.org. We ran test searches on all the engines and directories and found that GS returned more results and more citations, the fewest duplicate results and empty searches, and the broadest range of literature types. We also found that the search strings we were able to construct using GS's Boolean rules allowed us to be efficient with our search terms and search strings. Therefore, we conducted all searches using only GS.

3.1.4 | Building search strings

Using GS's Boolean rules, we built search strings of all possible combinations of our search terms. Each string included terms from each of our three essential categories: engineering, gender, and race/ethnicity. Examples of simple search strings can be seen below:

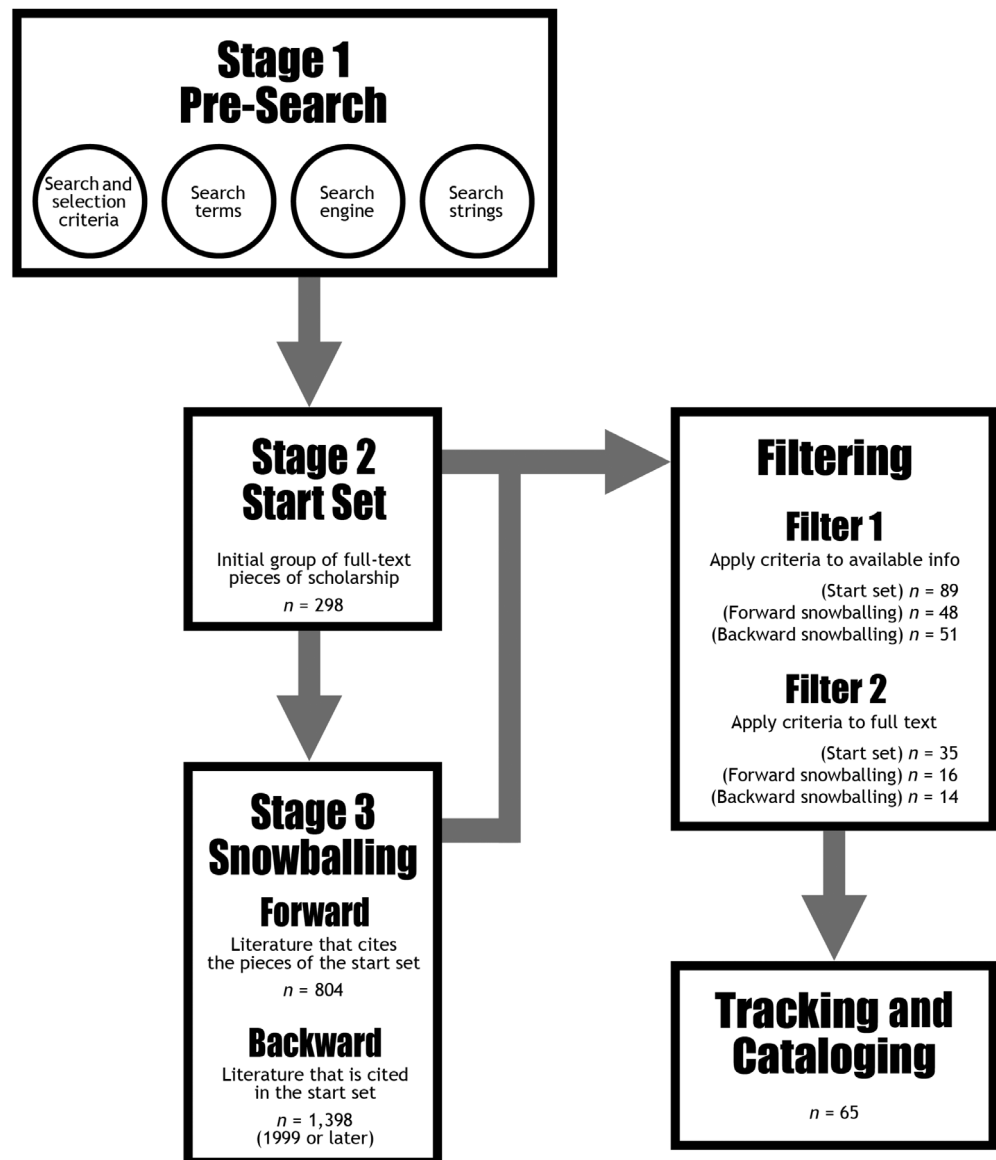
(engineer | engineering) (woman | women | gender | female | females) (Hispanic | Spanish | Latina | Chicana | Mexican)
 (engineer | engineering) (woman | women | gender | female | females) (Black | African | Afro)
 (engineer | engineering) (woman | women | gender | female | females) (Asia | Asian | Pacific)

The use of Boolean rules in the construction of the search strings ensured that at least one term inside each set of parentheses appeared in the titles of all the resulting literature. The rules allowed us to pull a comprehensive literature set while keeping our search terms relatively simple. For example, including "engineering" in the string returned titles from across engineering fields, such as civil, mechanical, computer, and environmental. We built a total of 131 search strings.

3.2 | Stage 2: Establishing the start set

Entering the search strings into GS's engine and limiting results to publication dates of 1999 to 2015 yielded an initial 298 results. To determine which of those studies would qualify to be part of the start set, we sifted those results through two filters. With Filter 1, we applied our search and selection criteria (Table 1) to the readily available information such as abstracts and titles. With this filter, we eliminated 209 pieces of literature (approximately 70% of the results) because the titles and/or abstracts clearly showed that the studies did not consider at least one of our three essential categories (race/ethnicity, gender, or engineering), which automatically disqualified them for inclusion in the synthesis. We also found a few studies that were not conducted in a U.S. context and, thus, did not qualify. Filter 2 was a quality control filter that ensured each piece met all the criteria, with an emphasis on intersectionality and on our quality appraisal filtering criteria to ensure that studies met our definition of empirical research. Of the studies remaining for this second filter, 54 pieces (approximately 60%) did not qualify for inclusion. Most of these studies were excluded due to lack of intersectionality; for example, they reported findings such as graduation rates for students of color in engineering OR for women in engineering, but they did not report on these rates for WOCE. We also found a few pieces that did not

FIGURE 1 Flowchart of the literature search, selection, and filtering process followed to find and select the literature included in the synthesis including the number of pieces of literature resulting from each step



pass the quality control filter because they did not include sufficient information about their research methodology, such as statements of how they analyzed their data or their research questions or purpose. Lastly, we solicited further resources from our advisory board and professional networks to double-check that our searches had not omitted any significant works. This solicitation resulted in nine new resources, of which we kept one. Filtering the results from the search and from the solicitation resulted in 35 studies qualified to act as our start set. See Figure 1 for a flowchart of our literature search, collection, and filtering steps.

Throughout the process, we cataloged citations, abstracts, and full text documents, and we tracked inclusion/exclusion decisions. Following Borrego et al. (2015), our team put in place a process to resolve any filtering questions that arose by consensus.

3.3 | Stage 3: Snowballing

We used the iterative process of forward and backward snowballing to expand the literature set with additional works. We began with forward snowballing, which consisted of identifying the works that cited our start set. We utilized GS's "cited by" feature in its search results page and found 804 "cited by" references. We applied Filters 1 and 2 to this literature as seen earlier. In Filter 1, we eliminated 756 pieces (approximately 94%) of the studies because they did not include at least one of our three essential categories or because they were not U.S.-based studies. In Filter 2, we

TABLE 2 Brief descriptors of empirical research on WOC in engineering higher education and careers, 1999 to 2015, included in the synthesis^a

Author/s and year	Literature format	Methodological stance	STEM field	Education level ^b	Race/ethnicity and gender descriptors
Alonso (2012)	Conference proceedings or papers	Qualitative	Engineering	Undergraduate	African American, Black, Hispanic, and Latina women
Alonso (2015)	Dissertation	Mixed methods	Engineering	Undergraduate	Latina/o women and men
Atwaters and Tao (2015)	Book chapter	Quantitative	Engineering	Undergraduate and graduate	African American, Asian, Black, Hispanic, and White women
Berry, Farmer Cox, and Main (2014)	Conference proceedings or papers	Quantitative	Engineering	Faculty	African American women
Brown (2000)	Dissertation	Qualitative	Science and Engineering	Undergraduate	Hispanic women and men
Brown (2008)	Peer-reviewed journal article	Qualitative	STEM	Undergraduate	Hispanic women and men
Bush (2013)	Dissertation	Qualitative	Engineering	Professionals	Black women
Camacho and Lord (2011)	Conference proceedings or papers	Qualitative	Engineering	Undergraduate	Asian, Latina, and White women
Chinn (1999)	Peer-reviewed journal article	Qualitative	Engineering	Undergraduate and early career	Polynesian and Filipina women
Chinn (2002)	Peer-reviewed journal article	Qualitative	Engineering, Physics, and Chemistry	Undergraduate	Chinese and Japanese women
Chowdhury and Chowdhury (2007)	Conference proceedings or papers	Quantitative	Engineering	Undergraduate	African American and Black women
Cruz-Pol and Colom-Ustáriz (2002)	Conference proceedings or papers	Quantitative	Engineering	Undergraduate	Hispanic women
DeCuir-Gunby, Grant, and Gregory (2013)	Peer-reviewed journal article	Qualitative	Engineering	Faculty	African American and Hispanic/Latina women
DeCuir-Gunby, Long-Mitchell, and Grant (2009)	Book chapter	Qualitative	Engineering	Faculty	African American, Hispanic/Latina, and Latin women
Eng and Layne (2002)	Conference proceedings or papers	Quantitative	Engineering	Professionals	Asian/Pacific Islander and Asian American women and men
Frehill (2004)	Conference proceedings or papers	Quantitative	Engineering	Undergraduate and graduate	African American, Asian American, American Indian, Hispanic, Mexican American and Puerto Rican, multi-racial, other Latino, and non-Hispanic White women and men
Frillman, Brawner, and Waters (2010)	Conference proceedings or papers	Qualitative	Engineering	Undergraduate	African American women

TABLE 2 (Continued)

Author/s and year	Literature format	Methodological stance	STEM field	Education level ^b	Race/ethnicity and gender descriptors
Gorman (2014)	Dissertation	Qualitative	Engineering	Undergraduate and staff members	African American, Hispanic, Native American, and White women and men
Hackler (2011)	Dissertation	Qualitative	STEM	Undergraduate	Black and Hispanic women and men
Jackson-Smith (2015)	Peer-reviewed journal article	Qualitative	STEM	Undergraduate	African American women
Lain and Smith (2012)	Report	Quantitative	Engineering	Undergraduate	African American, American Indian/Alaska Native, and Latino women and men
Leonard, Atwaters, Leggon, Pearson Jr, and Gaines (2013)	Conference proceedings or papers	Quantitative	Engineering	Undergraduate and recent graduates	Black women and men
Litzler, Mody-Pan, and Brainard (2011)	Conference proceedings or papers	Quantitative	Engineering	Undergraduate	African American, Asian American, Hispanic American, Native American and White women
Litzler and Samuelson (2013a)	Conference proceedings or papers	Qualitative	Engineering	Undergraduate	African American/Black, American Indian, Asian/Asian American, Asian Indian, Hispanic/Latino, White women and men
Litzler and Samuelson (2013b)	Conference proceedings or papers	Qualitative	Engineering	Undergraduate	African American, Latina/o, American Indian women and men
Lord and Camacho (2013)	Conference proceedings or papers	Mixed methods	Engineering	Undergraduate	Latina women
Lord, Camacho, Layton, Long, Ohland, and Wasburn (2009)	Peer-reviewed journal article	Quantitative	Engineering	Undergraduate	Asian, Black, Hispanic, Native American, and White women and men
Lord, Camacho, Layton, and Ohland (2010)	Conference proceedings or papers	Quantitative	Engineering	Undergraduate	Asian, Black, Hispanic, Native American, and White women and men
Lord, Layton, and Ohland (2011)	Peer-reviewed journal article	Quantitative	Engineering	Undergraduate, including transfer students	Asian, Black, Hispanic, and White women and men
Lord, Layton, and Ohland (2014a)	Conference proceedings or papers	Quantitative	Engineering	Undergraduate	Asian, Black, Hispanic, and White women and men
Lord, Layton, and Ohland (2014b)	Peer-reviewed journal article	Quantitative	Engineering	Undergraduate, including transfer students	Asian, Black, Hispanic, and White women and men
Lord, Layton, Ohland, and Orr (2013)	Conference proceedings or papers	Quantitative	Engineering	Undergraduate	Asian, Black, Hispanic, Native American, and White women and men

(Continues)

TABLE 2 (Continued)

Author/s and year	Literature format	Methodological stance	STEM field	Education level ^b	Race/ethnicity and gender descriptors
Lucero (2003)	Conference proceedings or papers	Qualitative	Science and Engineering	Faculty	African American women
Maldonado, Ramirez, Vazquez, and Medina-Borja (2007)	Conference proceedings or papers	Qualitative	Engineering	Undergraduate	Puerto Rican women and men
Marra, Rodgers, Shen, and Bogue (2009)	Peer-reviewed journal article	Quantitative	Engineering	Undergraduate	African American, Asian, Hispanic, Native American, White, and other minority ethnicity women
Martin, Simmons, and Yu (2013)	Peer-reviewed journal article	Mixed methods	Engineering	Undergraduate	Hispanic women
Mitchell (2014)	Dissertation	Qualitative	Engineering and STEM	Undergraduate	African American, Asian/Caucasian, Caucasian, Hispanic, and Mixed Race women
Montgomery (2009)	Dissertation	Qualitative	Engineering	Undergraduate	African American women and men
Morell (2002)	Conference proceedings or papers	Mixed methods	Engineering	Undergraduate and graduate	Latina women
Nelson and Brammer (2010)	Report	Quantitative	STEM, Engineering, Economics, Political Science, Sociology, and Psychology	Faculty	Asian, Black, Hispanic, Native American, and White women and men
Nelson and Rogers (2003)	Report	Quantitative	Science and Engineering	Faculty	Asian, Black, Hispanic, Native American, and White women and men
Oden (2003)	Dissertation	Qualitative	Engineering	Doctoral	African American and White women and men
Ohland, Brawner, Camacho, Layton, Long, Lord, and Wasburn (2011)	Peer-reviewed journal article	Quantitative	Engineering	Undergraduate	Asian, Black, Hispanic, Native American and White women and men
Ohland, Lord, and Layton (2015)	Peer-reviewed journal article	Quantitative	Engineering	Undergraduate	Asian, Black, Hispanic, and White women and men
Ohland, Orr, Layton, Lord, and Long (2012)	Conference proceedings or papers	Quantitative	Engineering	Undergraduate	Asian, Black, Hispanic, and White women and men
Ohland, Orr, Lundy-Wagner, Veenstra, and Long (2012)	Book chapter	Quantitative	Engineering	Undergraduate and graduate, faculty, professionals	Asian, Black, Hispanic, Native American and White women and men
Orr, Lord, Layton, and Ohland (2014)	Peer-reviewed journal article	Quantitative	Engineering	Undergraduate	Asian, Black, Hispanic, and White women and men

TABLE 2 (Continued)

Author/s and year	Literature format	Methodological stance	STEM field	Education level ^b	Race/ethnicity and gender descriptors
Parker (2013)	Dissertation	Qualitative	Engineering, Chemistry, Information Technology, Biology, Laboratory Animal Science	Undergraduate	African American women
Reyes (2011)	Peer-reviewed journal article	Qualitative	STEM	Transfer students (UG)	African, African American, American Indian, and Chinese women
Rice (2011)	Dissertation	Qualitative	Engineering	Professionals	African American/Black women
Rice and Alfred (2014)	Peer-reviewed journal article	Qualitative	Engineering	Professionals	African American/Black women
Ro and Loya (2015)	Peer-reviewed journal article	Quantitative	Engineering	Undergraduate	Asian, Black, Latina/o, Native American, and Caucasian/White women and men
Shain (2002)	Dissertation	Qualitative	Engineering	Undergraduate	African American women
Shehab et al. (2007)	Conference proceedings or papers	Qualitative	Engineering	Undergraduate	African American, Asian American, Hispanic, and Native American women and men
Simon (2011)	Conference proceedings or papers	Qualitative	Engineering	Professionals	African American women
Smith (2011)	Dissertation	Qualitative	Engineering	Undergraduate	African American, Asian, Caucasian, and Middle Eastern women
Somerville-Midgett (2014)	Dissertation	Qualitative	Engineering	Professionals	African American/Black women
Sosnowski (2002)	Dissertation	Qualitative	Engineering and Information Technology	Undergraduate and graduate	African American/Black, Latina, and White women and men
Tate and Linn (2005)	Peer-reviewed journal article	Qualitative	Engineering	Undergraduate	African American, Biracial (African American and White), Filipina, and Multiracial (Mexican/Mayan ancestry, Vietnamese, and White) women
Tharp (2002)	Dissertation	Mixed methods	Engineering	Professionals	African American, European American, Hispanic, and Native American women
Tran, Herrera, and Gasiewski (2011)	Report	Qualitative	STEM	Graduate	African American, Asian American, American Indian, Latina/o, Multiracial, and White women and men
Trenor, Yu, Sha, Zerda, and Waight (2007)	Conference proceedings or papers	Quantitative	Engineering	Undergraduate	African American/Black, Asian, Hispanic, White, and Multiracial women

(Continues)

TABLE 2 (Continued)

Author/s and year	Literature format	Methodological stance	STEM field	Education level ^b	Race/ethnicity and gender descriptors
Trenor, Yu, Waight, and Zerda (2008)	Conference proceedings or papers	Qualitative	Engineering	Undergraduate	Multiracial and Mexican American women
Trenor, Yu, Waight, Zerda, and Sha (2008)	Peer-reviewed journal article	Mixed methods	Engineering	Undergraduate	African American/Black, Asian, Hispanic, and White women
Vazquez-Akim (2014)	Dissertation	Qualitative	Engineering	Undergraduate and faculty	African American/Black, American Indian/Alaska Native, Asian, Multiracial, and White women and men

^aReaders should note that when we use gender and race/ethnicity descriptors in this table and throughout this text, we adhere as much as possible to the terms (e.g., Latina/Latino) used by each author in the literature referenced even though we recognize that language for race/ethnicity and gender identifiers is continually evolving (e.g., Latinx).

^bEducation level refers to the attainment levels of the subjects at the time of each study. Some pieces of literature contain contemporaneous data on the experiences of undergraduate women of color in engineering (WOCE) while others contain reflections on past undergraduate experiences by WOCE who went on to other attainment levels.

eliminated an additional 32 works (just over 66%) of the remaining results because they did not report on intersectionality or because they did not pass the quality control for empirical research. This resulted in 16 new pieces for the set.

We then applied backward snowballing to the start set, compiling and reviewing all the literature that the start set pieces cited in their bibliographies, and found 1,867 references. We eliminated the literature published before 1999 (our cutoff year), which removed 469 works (approximately 25% of the literature), for a total of 1,398. Implementing Filter 1 eliminated an additional 1,347 pieces (just over 96%) not relevant to this synthesis because of their lack of inclusion of at least one of our three essential categories or lack of U.S. focus, and Filter 2 eliminated 37 more pieces (approximately 72%) of the remaining references because they did not report on intersectional findings. Our backward snowballing process yielded 14 additional pieces.

The resulting body of literature that qualified for the synthesis was 65 studies (35 from the start set plus 30 from snowballing). See Table 2 for brief descriptors of the studies included in the synthesis (for a full list, see the Reference section).

3.4 | Coding

The team created a codebook through a hybrid approach that used both deductive and inductive coding (Fereday & Muir-Cochrane, 2006). This hybrid approach drew from our knowledge of the field through the use of the a priori codes the team had developed for previous work in STEM education (Ong et al., 2011; Ong, Smith, & Ko, 2018). The coding framework was organized around two main “parent” codes (person/support entity and action/type of support). These codes could be applied in an overlapping manner so that coded sections often included a “child” code from both categories. There were additional parent codes for recommendations/advice that we used for the development of the recommendations based on this synthesis and a “parking lot” for codes from the data to be considered for inclusion in the overall coding framework (see below for an example). See Table 3 for samples of codes included in the framework.

Some of the codes encompassed concepts from the literature on our theoretical frameworks. For example, both navigation (part of the action/type of support parent code) and family support (part of the person/support entity parent code) were codes that stemmed from Yosso's (2005) CCW theory.

We began applying the a priori codes to an initial sample of studies and modified the codebook when the new data did not fit. For example, the social comfort child code (part of the action/type of support parent code) was not part of the original coding framework. It developed as a parking lot code through several iterations of coding until it eventually became part of the overall codebook. Thus, this codebook was a living document and was periodically updated and refined by team consensus through an iterative process of coding, analysis, and recoding (Creswell, 2009, 2013; Glaser & Strauss, 1967).

TABLE 3 Coding framework used to code analytic memos (abbreviated)^a

Person/support entity	Action/type of support (or lack thereof)
1. Advisor/Supervisor	1. Identification/Self-expectations
2. Family	2. Navigation
3. Peers/Social Group	3. Social Comfort
4. Teacher/Professor	a. Isolation
5. Mentors	b. Prove-it-again
6. Internship	c. Recognition/Reputation
7. Support Programs	d. Spotighting
8. Professional Organizations	e. Microaggressions
9. Institution/Department	
Recommendations	Parking lot
1. For Institutions/Departments/Faculty	1. Work/Life and School/Life Balance
2. For women of color	2. Other
3. For future researchers	

^aThe coding framework used to code analytic memos included definitions and examples for each of the codes listed in the table. It is not possible include the full codebook due to its length.

3.5 | Analysis

We applied thematic analysis to the codes to develop our key themes. We looked for creative connections between the literature beyond the synthesis and the set of studies included in the synthesis in a process similar to abductive analysis described by Timmermans and Tavory (2012). For example, we found disparate literature describing how WOCE experience difficulties and barriers, such as racial discrimination and isolation, that stem from social interaction. Our team grouped this variety of difficulties under the psychology term social pain (Eisenberger & Lieberman, 2005) as an umbrella concept. This grouping provides additional theoretical background that was absent from the existing literature and allows for a deeper understanding of closely related phenomena based on the experience of negative social interactions. In other cases, some codes, such as support entities and navigation, were found so prominently across the literature that they emerged as part of our final themes.

From such groupings and connections with the literature, we identified four analytical themes: interest, motivation, and self-efficacy; social pain; navigation; and support entities. Our analysis focused on (a) these analytical themes, which elucidate the internal and external factors that support WOCE's success in undergraduate engineering education; (b) the implications of the findings for practice and policy; and (c) the topics that require additional research. These three areas form the core of this synthesis.

4 | LIMITATIONS

The limitations of this synthesis are primarily connected to our methodological choices. First, we decided to include empirical research on WOCE published only between January 1999 and March 2015. This decision was based on the belief that older research may no longer be relevant to the contemporary experiences of WOCE as well as the need to stop literature searches to advance to the next stage of the project. For the benefit of the reader, we conducted a cursory, nonexhaustive search of works on WOCE released between April 2015 and October 2019. The result was the 31 works listed in the Appendix.

Another limitation is the possibility that our definition of empirical research eliminated qualified studies even though we were relatively lenient in defining what constitutes the different components of a research study. Another limitation may be that we chose to use a single search engine to conduct our literature searches, and it may have not found all relevant works. However, it was supplemented by our snowballing process and by soliciting additional resources from our advisory board and professional networks, thereby casting a wide net to ensure the inclusion of works not otherwise captured. Another limitation is that the team did not disaggregate beyond race/ethnicity and gender by various social identities (e.g., class, sexuality, and ability status). However, given that most of the literature did not include disaggregation by these categories, analysis beyond race/ethnicity and gender would have been of

limited relevance. Finally, in the set of studies we synthesized, there was an imbalance in the representation of different racial/ethnic groups due to the fact that the literature itself focused more on some groups, such as African American women, than on others, such as Asian American and Native American women.

5 | FINDINGS

Our analysis of the 65 studies included in this synthesis resulted in four main analytical themes: interest, motivation, and self-efficacy; social pain; navigation; and support entities. Below we discuss how elements of each of these four themes influence WOCE's experiences and persistence in their undergraduate programs.

5.1 | Theme I: Interest, motivation, and self-efficacy

The literature showed that WOC were motivated to enter and persist in engineering for myriad of reasons, most prominently strong pre-college interest and academic preparation in STEM. Early interest in mathematics and science provided strong foundations for academic progress toward engineering studies in higher education (Bush, 2013; DeCuir-Gunby, Grant, & Gregory, 2013; Rice, 2011; Somerville-Midgette, 2014). Good grades, good scores on standardized tests, strengths in mathematics and science, and demonstrated capabilities relative to their male counterparts were also motivators in selecting to study engineering (Chowdhury & Chowdhury, 2007; Cruz-Pol & Colom-Ustáriz, 2002; Frillman, Brawner, & Waters, 2010; Morell, 2002; Smith, 2011). Moreover, attendance at pre-college engineering programs during high school influenced WOC's decisions to choose engineering studies in college (Bush, 2013; Tate & Linn, 2005). Strong interest in STEM, good grades, and high self-efficacy (discussed below) are common reasons for many students to pursue engineering. What makes the experiences of WOC unique in this regard is that they are persisting on engineering education trajectories in spite of strong, pervasive cultural messages that WOC do not belong in the field due to both their race/ethnicity and gender (Boucher, Fuesting, Diekman, & Murphy, 2017; Cheryan, Ziegler, Montoya, & Jiang, 2017).

Enjoyment, prestige, and anticipated financial reward were also noted to be motivations for entering and persisting in engineering education. Litzler and Samuelson (2013a) found that "enjoyment of engineering" (p. 3) was a top motivator for female (and male) Latina/o and Asian Indian students to persist in engineering once they entered college. A few studies found that WOC undergraduate students were motivated by perceptions that engineering was a well-paid profession and drew on what Yosso (2005) calls aspirational capital that, as engineers, they would provide a stable life for themselves and their families (Hackler, 2011; Litzler & Samuelson, 2013a; Morell, 2002; Trenor, Yu, Waight, & Zerda, 2008). For example, Morell (2002), reporting on a study of Latina undergraduate engineering majors at the University of Puerto Rico, Mayagüez campus, described participants as consciously thinking about engineering as generating high incomes as well as prestige.

Several works in our synthesis showed that WOCE selected and succeeded in engineering education because of their solid sense of self-efficacy, which is belief in one's own ability to succeed or accomplish a task (Bandura, 1982). Some studies found that high self-efficacy was a critical predictor of academic success and resulted from prior math and science courses in which they had excelled, as well as their acceptance into selective engineering programs (Bush, 2013; Lain & Smith, 2012; Maldonado, Ramirez, Vazquez, & Medina-Borja, 2007; Shain, 2002; Smith, 2011). Confidence grounded in family support or religious upbringing (Parker, 2013) also augmented their sense of self-efficacy and engineering persistence, pointing toward familial capital (Yosso, 2005) as further reinforcing self-efficacy. Furthermore, studies found that WOCE often held strong beliefs and expectations that they would achieve their academic goals and be professionally successful (Rice, 2011; Shain, 2002), and even become leaders in engineering (Shain, 2002; Somerville-Midgette, 2014; Sosnowski, 2002), suggesting aspirational capital (Yosso, 2005) as a driver of success. Morell's (2002) study highlighted Latinas showing high self-efficacy by entering a male-dominated career, stating, "they have taken particular pleasure in selecting a field that is still dominated by men; the thought of succeeding in that kind of environment is particularly appealing" (p. 12). For some WOCE, quitting engineering education was simply not an option, and they worked hard to prove to themselves and others that they could succeed (Litzler & Samuelson, 2013b; Rice & Alfred, 2014).

The literature also focused on the causes of low self-efficacy in WOCE, including perceptions of low academic ability (Mitchell, 2014; Parker, 2013; Vazquez-Akim, 2014); feelings of not belonging (Marra, Rodgers, Shen, & Bogue, 2009);

and attendant behaviors that negatively affect engineering pathways—such as an over-willingness to re-do coursework (Brown, 2008); questioning of their choice to enter engineering (Mitchell, 2014); underestimating their own academic abilities (Parker, 2013); and self-deterrence from persisting (Vazquez-Akim, 2014). Fortunately, the literature suggests that self-efficacy is not fixed and that there are ways, many of them involving social interactions, to increase it and thus WOC's persistence in engineering. These ways include identifying mathematics and science strengths (Chowdhury & Chowdhury, 2007; Cruz-Pol & Colom-Ustáriz, 2002; Marra et al., 2009; Smith, 2011); building engineering skills through internships (Hackler, 2011); successfully competing against strong students from other universities (Hackler, 2011); participating in supportive relationships, including personal and professional support from friends, peers, and mentors (Rice & Alfred, 2014; Shain, 2002); receiving genuine interest from program coordinators (Jackson-Smith, 2015); being asked to meet high expectations by mentors (Oden, 2003); and building networks in engineering through internships or student organizations (Brown, 2008; Shain, 2002). Unfortunately, many of these suggestions take an approach of “fixing” the student instead of seeking solutions from an institutional stance. In contrast, Brown (2008) explained the positive effects that engaging with student organizations focused on engineering had on the self-efficacy of Hispanic women participants:

By these young women being chosen and invited to be members of these groups, they were given confidence and purpose. They were given the message that they were a very important member of that school. ... Those who were involved ... blossomed in terms of being confident in many different situations. They found that they could do math and science and could be an important contributing member of the group. This was a valuable part of each one of these female student's lives, and each mentioned that this group helped her to successfully major in science or engineering. (p. 220).

This example at the organizational level shows that self-efficacy is not immutable and that institutional supports such as the ones cited above can have a positive impact on it.

Maldonado et al.'s (2007) study demonstrates on a much larger scale the impact of positive institutional supports on WOCE's self-efficacy. Maldonado and colleagues found Latina students at a Puerto Rican university to be highly confident of their acceptance into engineering due to teacher encouragement and having well-known women role models in engineering. Their participants felt capable and comfortable expressing their views in front of their male peers, and the majority was willing to enter jobs dominated by men. In this case, teacher support and role models, especially role models who are WOC, were pivotal supports for these women's self-efficacy.

Clearly, self-efficacy is a key support for success in engineering, a finding that resonates in the wider literature on WOC in STEM (Brownlee, 2004; Gwilliam & Betz, 2001; Espinosa, 2008, 2011; Vogt, 2005). Self-efficacy impacts both the intention to enter engineering studies and the ability to persist and succeed. Not all WOCE have a high degree of self-efficacy, however, and the literature demonstrates that self-efficacy can be modified and improved by institutional action to improve outcomes for WOCE. In spite of these findings, WOC remain underrepresented in engineering. As we will see in the next section, the literature indicates that one of the major issues is social pain.

5.2 | Theme II: Social pain

Across the literature, we found that WOCE experienced rejection from or lacked a sense of belonging to the predominantly White and male engineering environment. Their experiences were often rooted in intersectionality—their existing in engineering spaces as both female and non-White—and resulted from informal social dynamics and interactions with peers and faculty. We adapt the term social pain (Eisenberger & Lieberman, 2005) from the field of psychology to describe this set of experiences. Psychologists Eisenberger and Lieberman posit that when a human experiences social pain—including rejection, feeling left out, or feeling like one does not belong—it triggers a neural reaction that may be analogous to a reaction to physical pain. A physiological alarm goes off, interrupts current tasks, and focuses attention on mitigating the pain source. The reaction is “distressing, attention-getting and disruptive” (Eisenberger & Lieberman, 2005, p. 117). Our team describes social pain as diverting WOCE's cognitive resources away from the study and practice of engineering and toward the managing of their social environment. The literature in our study identified four types of social pain: being the only one; being made invisible; stereotype threat and being spotlighted; and discrimination and harassment.

5.2.1 | Being the only one

The literature revealed that WOCE experienced a sense of isolation stemming from being the only one of their gender and/or race/ethnicity in engineering classrooms that were populated mostly by White men. The social pain of isolation manifested as loneliness (Alonso, 2012; Parker, 2013); the inkling that they were serving as racial, ethnic and/or gender tokens (Bush, 2013); the sense that no one else in the department fully understood them (Bush, 2013; Frillman et al., 2010; Parker, 2013); having few professors or other role models who looked like them (Nelson & Brammer, 2010; Nelson & Rogers, 2003); and/or anxiety that they were being excluded from important study groups and networks (Rice, 2011; Tate & Linn, 2005).

In Sosnowski's (2002) study of undergraduate WOC in engineering and other technology-related fields, one African American engineering major recounted her sense of loneliness: "There is really no one you can talk to that's going to relate with the things that you have to deal with on a day-to-day basis as [an] African American female in engineering" (p. 137). Underscoring the effects of social pain, Tate and Linn (2005) noted that WOCE in their study "find difficulty in forming and participating in study groups because of their racial or ethnic difference" and warned that their social identities could be "characterized by feelings of difference and [a] lack [of] sense of belonging" (p. 488). Being the only one effectively isolates WOC from the majority of the engineering students and may result in their questioning their placement in their program. For example, one participant in Mitchell's (2014) study reflected on how her isolation might affect her persistence: "I was concerned there were too few black engineers and I was not sure I would be able to successfully complete an engineering program in college" (p. 78).

5.2.2 | Being ignored or made invisible

Being ignored or made invisible yields particular kinds of social pain for WOCE. Research on WOC students and professionals in engineering and other STEM fields (Carlone & Johnson, 2007; Obiemon, Tickles, Wowo, & Holland-Hunt, 2007; Rincon & Yates, 2018) has demonstrated that when meaningful others, such as professors or peers, recognize a WOC as a competent, emergent STEM professional, it can build her STEM identity. Conversely, withholding such recognition can exacerbate a sense of not belonging. Several studies in our synthesis described how White male professors and peers routinely exercised their power to ignore or make invisible WOCE in classrooms or study groups (Alonso, 2012; Bush, 2013; Camacho & Lord, 2011; Lord & Camacho, 2013; Reyes, 2011). An African American woman in Bush's (2013) study described a commonly reported incident: "If you had questions or anything and asked a question, the teacher would ignore it. But if a White man asked the same question, they would say okay, that's great. And it was just a lot of slights and how we were treated differently" (p. 85).

When clustered with White students, Asian American engineering students can also experience the social pain of being made invisible and ignored. Ro and Loya (2015) stated that when Asian American students are grouped with Whites in engineering and science, any "low levels of self-efficacy and confidence" could go unrecognized and contribute to academic struggles, as Asian American students are "less likely to seek support, unknowingly limiting the resources and capital that other students benefit from, and potentially undermining their ability or at least the self-assessment of their skills" (p. 386).

When White male peers ignore the contributions of WOCE during classroom group work and assign them, instead, to ancillary roles like note-taker, they effectively demote the social status of the latter and negate their intellectual potential. Camacho and Lord (2011), observing such a phenomenon among undergraduate Latinas in their engineering courses, noted that such experiences isolated them from their majority peers and made them invisible as contributing group members; these Latinas then had to redirect their focus from the task at hand to solving the social situation. One African American engineering student in Parker's (2013) study described a similar experience of the social pain of being made invisible:

It's just very awkward to have to go into a room and be the only person of color. You know you don't have anybody. It was like that in the beginning but you don't have anybody to talk to. When we are assigned projects, we are split into teams and they weren't very receptive. It was almost as if they were talking over me, not like I was speaking and they were talking over me. I was sitting in the middle of two of my group mates and they were talking to each other over me. (p. 100).

5.2.3 | Stereotype threat and being spotlighted

Stereotype threat is a situational predicament in which a person feels at risk of confirming a negative stereotype (e.g., unintelligent, bad at mathematics, and not athletic) about a group of which that person is a member (Steele, 2010). Stereotype threat causes stress and debilitates performance in ways that do not affect members of nonstereotyped groups in the same context (Spencer, Steele, & Quinn, 1999; Steele, 1997, 2010; Steele & Aronson, 1995).

Our study revealed that, like other minoritized groups, WOCE carried the burden of disproving negative stereotypes about their group's intellectual abilities in engineering. In Oden's (2003) comparative study of African American and White doctoral students in an engineering department, one African American woman reported, "At first, I didn't get the personal guidance that I needed. The only feedback I received seemed too general. It seems like I had to prove my worth intellectually before my advisor spent quality time with me" (p. 95). Several studies noted WOCE's observations that, conversely, their White male colleagues did not carry the same burden of proving themselves (Camacho & Lord, 2011; Oden, 2003; Parker, 2013; Rice & Alfred, 2014; Shain, 2002). Litzler, Mody-Pan, and Brainard (2011) and Lord and Camacho (2013) suggest that the scarcity of WOCE in higher education contributes to their vulnerability to stereotype threat and reinforces existing stereotypes about who is capable and who belongs.

Being singled out on the basis of an aspect of one's social identity, otherwise known as being spotlighted (Carter, 2007; Carter Andrews, 2012; McLoughlin, 2005), can exacerbate stereotype threat for WOC. This is especially so if spotlighting is initiated by an authority figure, such as a professor calling on a single African American woman to be the voice for all African Americans. Litzler et al. (2011), who studied a large, racially/ethnically diverse group of undergraduate women in engineering, found that survey data from students at 21 schools showed that African American women, in particular, experienced a disproportionate amount of racial stereotyping and being singled out. The researchers noted, "Stereotypes in and of themselves can make individuals from the stereotyped group feel like they do not belong. Being singled out in class because of one's racial or ethnic background creates an even more hostile climate" (Litzler et al., 2011, p. 8; see also Parker, 2013).

5.2.4 | Discrimination and harassment

Lastly, several studies suggested that WOCE experienced social pain as a result of discrimination and harassment by professors and peers. In interactions with undergraduate peers and faculty in engineering, WOCE reported being sexually harassed (Gorman, 2014); being the subject of subtle or overt racism or sexism (Bush, 2013; Camacho & Lord, 2011; Reyes, 2011; Shehab et al., 2007), and having their abilities and academic qualifications questioned (Brown, 2000; Camacho & Lord, 2011). For example, Camacho and Lord (2011) described male undergraduate peers undercutting Latinas' achievements by ascribing them to affirmative action, irrespective of the fact that the Latinas' grades and standardized test scores were consistently higher than their peers'. Sexual harassment and discrimination were also evident in a few studies. For example, Gorman (2014) described one WOC engineering student, Terri, who knew she was going to fail a class because her male instructor gave her "straight 69s" on all her homework and tests. Gorman stated, "A score of 69, with sexual undertones and all, is not considered a passing grade in engineering. A consistent score of 69 'on everything' that Terri received somehow felt wrong" (p. 222). This same student recounted male peers in her program joking with female students about the females getting A's only because they "have boobs" (p. 200).

The literature shows that social pain is widely experienced in many forms by WOC in the engineering environment; that this pain can negatively impact their performance, persistence and retention, regardless of their levels of interest, motivation and self-efficacy; and that the social pain experienced in engineering schools replicates culturally pervasive race and gender inequities. Social pain diverts WOCE's cognitive resources away from their engineering education and toward navigational strategies, as described below.

5.3 | Theme III: Navigation

The literature revealed a wealth of navigational strategies that WOCE used not only to cope with the rigors of engineering education but more often to overcome social pain. These strategies evoke Yosso's CCW concept of navigational capital, which is the ability to maneuver through social "institutions not created with Communities of Color in mind" (Yosso, 2005, p. 80), such as engineering programs in U.S. higher education. The strategies also reveal students'

deploying linguistic capital (adaptable and multicultural communication skills) and resistant capital (oppositional behavior to challenge inequities; Yosso, 2005). The strategies we identified from the literature fall into four main categories: (a) modifying internal dialogue and behaviors; (b) cultural adaptation; (c) cultural self-affirmation; and (d) giving back.

5.3.1 | Modifying internal dialogue and behaviors

WOCE demonstrated multiple tactics to achieve and cope with struggles by modifying their internal dialogue and behaviors. As Parker (2013) asserted, this may be because study participants “concluded that differential treatment or sexism was something they would have to accept and learn how to work around, especially for those women in male-dominated STEM fields” (p. 111). WOCE recognized the contradictions between their identities and the engineering context (Gorman, 2014; Parker, 2013). However, rather than changing the cultural context, they modified their own behaviors and expectations in response to “the contradictions they saw, experienced, and/or knew so that they could persist in the culture ‘as is’” (Gorman, 2014, p. 198). WOCE’s internal modifications included denying their own cultural identity by passing as White and tolerating racism by ignoring racist remarks or ignoring the circumstances in which they were made invisible. Additionally, Gorman (2014) reported an avoidance strategy of letting uncomfortable comments slide. However, Brown (2008) found that some of these strategies were not employed without regret by some Hispanic participants. WOCE also modified their internal dialogue and behavior by practicing self-care, faith, and prayer to cope internally with discrimination (Bush, 2013).

5.3.2 | Cultural adaptation

The literature describes other WOCE engaging in cultural adaptation by adopting the dominant engineering culture through their language, behavior, and appearance choices. This helped them to acclimate to the engineering culture or gain access to the social networks of those in powerful positions (Chinn, 1999; Gorman, 2014; Parker, 2013). For example, Chinn found that, to fit into their engineering environments, Asian and Pacific Islander women students engaged in nonfeminine dress, assertive behaviors and displays of confidence, overt athleticism, and/or reduction of emotions and reactions (Chinn, 1999, 2002; also see Gorman, 2014; Parker, 2013). Chinn (2002) further underscored how almost being perceived as male was integral to one Asian American woman participant’s identity in engineering, who preferred “competing against males in terms of competence instead of competing against females based on physical attractiveness” (p. 313).

WOCE also culturally adapted to their predominantly White and male spaces by skillfully communicating with their peers (Montgomery, 2009; Oden, 2003). Such communication adaptations relate to Yosso’s (2005) idea of linguistic capital, which includes code switching and developing multiple styles to relate to different audiences. An African American student in a study conducted by Oden (2003) expressed the need to “choose [her] words a little more carefully” due to the feelings of “constantly being examined for the level of [her] intelligence and communication skills” (p. 110). In Montgomery’s (2009) study, an African American woman shared the “importance of ‘making the switch’ and developing a ‘habit of fitting into your surroundings’” when in predominantly White environments (p. 111). However, for WOCE, it is not always easy nor desirable to shed their multiple identities for the sake of adapting to the predominant engineering culture (Alonso, 2012).

5.3.3 | Cultural self-affirmation

Conversely to those adopting the dominant culture, some WOCE defied opposition to their presence in engineering by choosing cultural self-affirmation with strategies like back talk, confrontation, and resistance to marginalization. These affirmational strategies align with Yosso’s CCW concept of resistant capital that challenges inequality, which includes practicing resistance individually and in groups, and passing on oppositional practices to others (Yosso, 2005). For example, in Chinn’s (1999) study, Polynesian and Filipina women participants back talked “to counteract the power of negative racial and gender discourses” (p. 630). Similarly, WOCE in Gorman’s (2014) study confronted gender stereotypes and called out instructors who tried to humiliate them in the presence of their peers. When Latina participants in

Lord and Camacho's (2013) study felt ignored or marginalized, they defended themselves by “sticking to [their] guns” (p. 564) or standing up for themselves.

5.3.4 | Giving back

Finally, the literature points to WOC using the navigational strategy of giving back, which helped to develop their engineering identities and served as a motivational theme for their persistence in engineering. Alonso (2015) found that “commitment to the community was integral to [the] engineering identity development” (p. 63) of Latina/o undergraduates. This was demonstrated through, for example, collaborating with their local Society of Hispanic Professionals in Engineering chapter to do community outreach or organizing *Noche de Ciencias* (Science Night) to teach science concepts to children from the community. Multiple authors found that this drive to give back—by helping those who were struggling, contributing to the accomplishments of their race/ethnicity, or becoming a role model—motivated African American and Latina women to complete their engineering programs (DeCuir-Gunby et al., 2013; Shain, 2002). Participants in Mitchell's (2014) study reported wanting to increase the number of students of color and women in the engineering field: “the high demand for women and minorities in engineering and STEM fields were of the utmost importance to motivating the participants to complete their programs in college” (p. 82). Trenor et al.'s (2008) study suggests that giving back may be a navigational strategy more characteristic of WOCE than other groups. They found that African American/Black and Hispanic women participants wanted to give back to their families, communities, or younger girls, whereas Asian and White women in their study did not explicitly declare having similar desires. Trenor et al. (2008) expressed surprise about their finding about Asian women given previous research indicating high levels of family obligation in Asian American youth (Fuligni & Pedersen, 2002).

The literature shows WOCE protecting themselves from social pain with the use of different navigational strategies in order to persist within the dominant culture of engineering. Engaging these strategies is an expense of time, energy, and cognitive resources for WOCE—in addition to their course load—that can impact persistence and success (Brown, 2008; Gorman, 2014; Rice & Alfred, 2014; Shain, 2002). In the Discussion section below, we will address how institutions might learn from such strategies and develop them into institutional supports for WOCE. Next, we describe how support entities, from the individual to the program level, are a protective factor for WOCE navigating engineering pathways and environments.

5.4 | Theme IV: Support entities

Our synthesis identified multiple and varied organizations, programs, groups, and individuals that support WOCE to better navigate experiences of social pain and persist in their studies. Three categories of support entities appeared as central for supporting WOCE to complete their degrees: family, peers, and programs. These groups may be considered safe spaces, or counterspaces (Ong et al., 2018; Carter, 2007; Solórzano et al., 2000; Solórzano & Villalpando, 1998), that help to counter the effects of social pain and affirm WOC's belonging in engineering. Furthermore, applying and extending Yosso's CCW framework, we see these support entities as representing familial capital, as they help WOCE maintain ties to their communities and resources and reduce their sense of isolation (Yosso, 2005; see also Villalpando & Solórzano, 2005). These support entities also represent social capital, which refers to a network that provides the individual with emotional support and reassurance that WOCE are “not alone in the process of pursuing higher education” (p. 79). Of the successful support systems found in the literature, it is notable that they are rarely constituted by a single, one-to-one relationship. More typically they are made up of networks and combinations of support entities. This aligns with findings from Vazquez-Akim (2014) indicating that WOC who do not persist in engineering are “less likely to reference a network of multiple and varied sources of support” (p. 107).

5.4.1 | Families

The literature showed that families, especially mothers, played a central role in providing emotional support by nurturing, motivating, comforting, and encouraging WOC to persist in their engineering studies (Brown, 2000, 2008; Chinn, 1999; DeCuir-Gunby et al., 2013; Rice, 2011; Shain, 2002; Simon, 2011). Parents inspired their children to

achieve more than they themselves had (Simon, 2011); made sacrifices to enable their children's access to educational resources and to show their pride in them (Chinn, 1999; Rice, 2011); provided guidance and occasionally role models (Shain, 2002); and instilled a sense of responsibility (Brown, 2000). Brown (2008) showed that among Latina science and engineering students, mothers pushed their daughters to succeed in their education by instilling a fear of becoming pregnant before finishing their degrees, which the mothers argued would trap them in traditional gender roles. However, the family's role could be contradictory, and even become a roadblock to persistence, due to a lack of understanding of the daughter's chosen path of study (Gorman, 2014); concerns about the daughter deviating from their traditional gender and cultural roles (Brown, 2008); or unwelcome pressure to succeed and be a role model for younger generations (Gorman, 2014).

For some WOCE, family played an important role by transmitting spiritual principles that became emotional tools for coping with hardship (Somerville-Midgette, 2014; Sosnowski, 2002), for example, the use of faith and prayer as a navigational strategy (Bush, 2013). Under Yosso's (2005) definition of family to include kin and broader support systems, church affiliation, as connected to family life, appeared to be an important support. In some cases, church could be a proxy for family, providing role models and guidance as reported by a WOCE participant in Bush's (2013) study:

I think that if I hadn't been so involved in my church back where I grew up and seeing all types of African Americans in various leadership roles, I don't know where I would have been. Because, again, I saw all the different opportunities and they were always open to discuss or talk to or guide you if you expressed an interest in something. My mom didn't know anything about this or she didn't have expertise but she knew we'd go to church and she would basically say go talk to such and such so they can help you. (p. 84).

5.4.2 | Peers

The research literature suggests that undergraduate student peers within and outside engineering routinely played key roles in supporting WOCE's persistence. Tate and Linn (2005) found that "students maintain[ed] separate academic and social peer networks with distinct members and purposes" (p. 489). WOCE maintained peer groups within their discipline to reinforce their identity as engineers and for academic support, whether or not those peers shared their gender or ethnicity (Hackler, 2011; Litzler & Samuelson, 2013b; Martin, Simmons, & Yu, 2013; Rice, 2011). These peers provided support in their successful use of navigational strategies. In addition, WOCE cultivated groups of peers with their same cultural background, or from other minority groups, regardless of academic discipline (Oden, 2003; Shain, 2002). Members of these groups provided a broader range of support, encompassing emotional encouragement, social comfort, the celebration of their cultures, and connection over common experiences of rejection (Alonso, 2015; Brown, 2008; Oden, 2003; Rice, 2011; Shain, 2002; Simon, 2011). Peers from the same or similar cultural backgrounds provided safe social environments that were respite from social pain.

In some cases, peers from both the same discipline and from a minoritized group provided academic as well as emotional/social support. A WOCE participant in Rice's (2011) study recalled an early undergraduate experience:

My first quarter there, and I'm like, I have to get a team and nobody wanted me to be on their team. With one exception, and it never failed; it happened every class, the students from other countries, who were of color. The first time one of them came to me, and said ... "you know I'm being rejected by my classmates, no one wants me to be ... a part of their team, and so I'm just assuming that the same thing is happening to you, is that true?" I said "yes" (and they said) "so why don't we get together and have our own team?" ... And guess what, these students were always the smartest in the class. I was like "ok I got the hook up!" (p. 204).

By teaming up, these students avoided the social pain caused by the rejection of the other students and successfully leveraged navigational strategies of collaboration with capable peers.

5.4.3 | Programs

Programs and organizations to support engineering students typically included a combination of services and supports that fostered the creation of social networks. As such, they provided a foundation for the network or combination of

support sources that Vazquez-Akim (2014) identified as critical for persistence. This type of network provided the grounds for increased self-efficacy and reduced social pain among WOCE. The existing research literature covers a wide diversity of support programs for WOCE: pre-college, community college to college transition, residential, for women and/or minorities, summer programs, and student organizations. We found the four points of convergence around the benefits they provided described below.

Access to a peer network for social and academic support

Programs and organizations provided WOCE with access to a variety of supports that included a cohort of peers going through the same experiences and courses (Brown, 2000; Litzler & Samuelson, 2013b); a sense of community and friends (Brown, 2008; Litzler & Samuelson, 2013b); the formation of future professional networks (Rice, 2011); help in acclimating to campus (Rice, 2011; Rice & Alfred, 2014); help in navigating educational and professional paths (Rice & Alfred, 2014); and an overall sense of diversity in the school (Vazquez-Akim, 2014). For example, the African American women in the pre-college program that Rice and Alfred (2014) studied built a women's supportive peer network that helped them acclimate to campus. Litzler and Samuelson (2013b) found that students in residential programs with long-term study groups for academic support built "lasting relationships that [saw] them through college" (p. 16).

Source of self-confidence and motivation to persevere

Participation in programs and organizations helped give WOCE a sense of personal worth (Brown, 2008); a sense of competency in disciplinary areas (Brown, 2008; Hackler, 2011); a sense of belonging in the group (Brown, 2008; Reyes, 2011); and self-confidence when considering the workforce or graduate school (Hackler, 2011). For example, Brown (2008) found that Hispanic students who were invited to participate in academic summer programs became confident and purposeful and were given the message that they were very important members of the school. Hackler (2011) found that participation in a project in a research center strengthened WOCE students' self-perception and self-confidence in their engineering skills so that they felt that they could compete in the job market.

Relationships with program and university staff

Personnel such as program staff and university administrators provided a broad array of supports to WOCE that spanned the academic, professional, and personal spheres of students' lives. These included emotional supports, such as positive recognition (Alonso, 2012) and motivation and encouragement (Rice & Alfred, 2014; Shain, 2002); mentoring and counsel, such as honest advice and first-hand accounts (Jackson-Smith, 2015); and general academic and social support (Rice, 2011; Shain, 2002). These staff members also connected WOCE to supports and resources by, for example, introducing them to key players who could help them in the future (Litzler & Samuelson, 2013b); serving as resource brokers for access to tutoring, internships, and professional organizations (Litzler & Samuelson, 2013b; Reyes, 2011); and providing resources around financial aid and scholarships (Rice, 2011; Rice & Alfred, 2014). Rice (2011) found that program staff provided social comfort in the university environment as well as help in navigating educational and professional paths. Furthermore, Rice and Alfred (2014) found that the on-campus support provided by university administrators served as a surrogate familial support system.

Use of on-campus resources to find additional career-related opportunities

WOCE's participation in programs and organizations helped them find career-related opportunities that would have not been otherwise accessible, such as funding (Hackler, 2011; Reyes, 2011; Rice & Alfred, 2014); internships (Hackler, 2011); research projects (Litzler & Samuelson, 2013a; Reyes, 2011); and tutoring (Litzler & Samuelson, 2013a). For example, Litzler and Samuelson (2013a) found that WOCE students who engaged with on-campus organizations, such as the Society of Women Engineers (SWE) or offices for diversity, found opportunities to conduct research. Reyes (2011) found that "retention was higher among Futurebound [a National Science Foundation-funded program] students who were engaged in programmatic efforts focused on supporting and nurturing women of color, with attention paid to their specific challenges and strengths" (p. 255).

Across the literature regarding programs, we continually encountered the theme of students wanting and needing these networks to re-create a surrogate family support system. The highest praise that study participants could confer on a program, organization, individual, or group was that they were like "a home away from home" or "like family" (Alonso, 2015; Parker, 2013; Rice, 2011; Rice & Alfred, 2014; Shain, 2002). The sense of family-like support most often developed around community gatherings that provided members with social and academic forms of support. These gatherings could be either formal, such as the regular meetings in the Meyerhoff Scholars Program at the University of

Maryland (Rice, 2011), or informal, such as those in two engineering schools in the Northeast (Shain, 2002) that included cultural foods and music and the sharing of common experiences and information. Students reported that feeling like they belonged was key, potentially buffering them against the social pain of being the only one, being ignored, or being made invisible. These same supportive relationships had the potential to aid the development of stronger self-efficacy among WOCE, as we have seen earlier.

From our analysis of key support entities described in the literature, we see that some engineering institutions provide a broad range of supports and promote the creation of social networks that reproduce a family-like environment. Such environments promote a sense of belonging, which reduces social pain and improves student self-efficacy, which in turn can improve persistence and retention. Below, we discuss the implications of these findings for institutional practices and policies in support of WOC in engineering education.

6 | DISCUSSION

In this systematic thematic synthesis, we have covered a broad array of factors revealed by the literature that affect the experiences, participation, and advancement of WOC undergraduates in engineering higher education. The theoretical frames of CRT (Bell, 1995; Solórzano, 1997; Solórzano et al., 2000) and intersectionality (Collins, 2000; Collins & Bilge, 2016; Crenshaw, 1991, 1993) bring into high relief how systemic gendered and raced oppressions continue to be experienced in traditionally White and male spaces, such as engineering education in particular, and in unique ways by persons who embody intersecting, marginalized racial/ethnic and gender identities (Pawley, 2013, 2019). The CCW framework (Yosso, 2005, 2006; Yosso et al., 2009) assists in understanding resiliency and persistence despite lived experiences of social pain. We continue Denton et al.'s (2020) and Samuelson and Litzler's (2016) application of CCW in the STEM/engineering context, with a deeper focus on WOC. We developed four main themes described in the literature that encompass the experiences of WOCE in undergraduate programs: interest, motivation, and self-efficacy; social pain (Eisenberger & Lieberman, 2005); navigation; and support entities. Our analysis allowed for new groupings of data that shed light on the ways that these factors support or hinder persistence and retention. Additionally, we found insight into the interplay between internal, individual motivational factors and external, structural supports, including institutional interventions, as they relate to WOCE's participation and success. While this synthesis is specific to WOCE, its findings and analysis may be relevant to other STEM fields, especially physics and computer science, where WOC are similarly underrepresented (NSF/NCSES, 2019).

The internal factors that we found motivating WOCE to participate and persist in engineering include the promise of financial security for themselves and their families (a form of aspirational capital, as described in Yosso, 2005); interest in and preparedness for STEM studies; enjoyment of engineering in particular; and self-efficacy. Although much of the literature points to self-efficacy (or the lack thereof) as an important aspect of WOC's persistence, historically, focusing only on student self-motivation has led to deficit-oriented models for supporting students of color in education (Samuelson & Litzler, 2016) and has inequitably located the burden of persistence on WOC (Ko, Kachchaf, Hodari, & Ong, 2014; Vazquez-Akim, 2014). However, our study reveals that student self-efficacy is malleable through outside intervention, especially by support entities (Brown, 2008; Hackler, 2011; Jackson-Smith, 2015; Shain, 2002). The study also identifies the factors for successful support systems for WOCE: a complex strategy composed of various social networks that cultivate a family-like atmosphere and sense of belonging (Alonso, 2015; Vazquez-Akim, 2014). Informed by CRT and intersectionality theory, we urge programs and institutions of higher education to take responsibility for changing the engineering education environment by developing such systems and supports that strengthen WOCE's self-efficacy, and thus their persistence and retention in engineering. These interventions will recognize that gendered and raced oppressions are still prevalent and institutionalized in engineering education programs and will be grounded in asset-based approaches in which WOCE's cultural backgrounds are treated as strengths, not deficits.

Institutionalized inequities appear throughout the literature, captured in WOCE's experiences of social pain (Eisenberger & Lieberman, 2005) in its different forms (i.e., being the only one, isolation, being made invisible, stereotype threat, and discrimination and harassment). As intersectional beings (Collins & Bilge, 2016; Crenshaw, 1991, 1993), WOC experience increased social pain in environments such as engineering higher education that are traditionally designed for the success of White, male students. We identified four categories of navigational strategies being utilized by WOCE to mitigate the impacts of social pain: modification of internal dialogue and behaviors, cultural adaptation, cultural self-affirmation, and giving back. Such strategies draw on the cultural wealth of navigation, linguistic, and resistant capital (Yosso, 2005). The dynamic and interacting nature of cultural capital (Samuelson & Litzler, 2016) is

evident in strategies such as cultural adaptation (navigation/linguistic) and cultural self-affirmation (navigation/resistant). Implementing navigational strategies to protect from social pain is a diversion of resources—cognitive, emotional, time, and social capital—not required of students who already “fit” the norms of the dominant engineering culture. To expect WOCE to continually engage in these navigational strategies to lessen the impact of social pain on their education experience is to misplace responsibility for addressing, resolving, and eliminating institutional inequities. Support entities are the factor in the literature tied most closely to WOCE persisting in their programs. The literature shows that WOCE who have multiple and varied sources of support are more likely to be successful. Three categories of support entities emerged as central: family, peers, and programs. These findings align with the CCW framework (Yosso, 2005), which claims that such entities activate familial and social capital, creating a sense of belonging through networks and an expanded sense of family. One key finding is that WOCE expressed a need and desire for programs that recreate surrogate familial support systems that provide them with a sense of caring and of belonging as counterpoints to experiences of social pain.

In other words, the same qualities in support entities that improve the positive internal factor of self-efficacy—complex, varied, and fostering belonging—also decrease the negative external factor of social pain. This suggests institutions can and should create programs and supports that utilize forms of CCW—for example, familial and social capital—that are already assets for WOCE. These supports, of course, do not happen on their own, so institutions need to initiate and sustain them with policies and systematic training efforts. Below are recommendations based on the literature for both formal and informal supports that institutions of higher education should put in place to provide the network of support and sense of belonging that will allow them to retain and graduate successful WOCE.

7 | RECOMMENDATIONS TO INSTITUTIONS, DEPARTMENTS, FACULTY, AND STAFF

For at least two decades, many U.S. institutions have sought to recruit WOC into their engineering programs in response to a call from the National Academy of Engineering to diversify engineering (Wulf, 2002) or from industry's demand for creative solutions from a strong, diversified workforce (Gibbs, 2014; Page, 2007). Often, however, any supports provided as recruitment tools (e.g., summer bridge programs) to entice WOC and other underrepresented students to enroll typically disappear once those students enter their programs (Chang, Sharkness, Hurtado, & Newman, 2014). Retention efforts are often scarce, yet when institutions do offer them, they are usually rooted in deficit models that seek to “fix” the students, for example, by providing tutoring or teaching them “self-confidence,” rather than addressing oppressive institutional practices through full-scale structural and cultural reforms (Malcom & Malcom, 2011; Ong et al., 2018; Valencia, 2010). We posit that the reason diversity efforts do not succeed on a larger scale is because current approaches are rooted in the expectation that WOC and other non-White or women participants in engineering conform to institutional cultures designed to exclude them. Below, we provide a set of recommendations that seek to take the burden of conformity off of WOCE and that subvert the typical approaches by suggesting ways that institutions can change to become places of belonging for all students. These changes require engaging in the hard work of recognizing that these institutional cultures and expectations stem from a history of gender and racial/ethnic discrimination in which White men have been held up as the standard and embodiment of success. We acknowledge that it can be daunting to develop a course of action to address these challenges, but this literature synthesis has revealed a set of actionable strategies, drawn directly from on-the-ground research on experiences of WOC in undergraduate engineering programs. These recommendations can be implemented by institutions, departments, faculty, and staff to recruit and support WOCE so that they can persist and succeed in engineering higher education and institutions can begin to change their cultures. These strategies are only a starting point; institutions, departments, faculty, and staff should also seek to learn from their own students' experiences to build on these recommendations with actions that are customized for their own student population and departmental and institutional contexts.

7.1 | Outreach and recruitment

The literature on WOCE demonstrates that if higher education institutions are interested in increasing WOC in their undergraduate engineering student bodies, they must take the long view and make a long-term investment in recruitment. The literature shows that successful institutions and departments developed multiyear relationships with local

middle schools, high schools, and community colleges. These institutions made consistent, multiple efforts to engage girls and young WOCE using a variety of strategies, including hosting workshops and summer courses that introduced them to and engaged them in engineering (Bush, 2013; Tate & Linn, 2005); exposing WOCE to role models of similar racial/ethnic and gender backgrounds (Maldonado et al., 2007; Rice, 2011); cultivating mentorships (Lord, Camacho, Layton, & Ohland, 2010); and holding workshops and summer programs explicitly for WOCE, recognizing that they may have needs distinct from those of White women and men of color (Reyes, 2011; Trenor, Yu, Waight, Zerda, & Sha, 2008). Institutions and departments that emulate these actions would help plant seeds of self-efficacy and increase awareness about engineering knowledge and careers for younger generations of WOC, while benefiting from effective recruitment tools in their own institutions and engineering programs (Chowdhury & Chowdhury, 2007). Reyes (2011) indicates how these recruitment efforts can effectively expand to WOC in community colleges and notes strong articulation agreements, regular communications between faculty at the university and its community colleges, and regular invitations for current community college students to take engineering-related courses and conduct research at the university. Through persistent outreach and long-term recruitment strategies, institutions and departments could increase the number of WOCE in undergraduate programs, thus creating environments with a critical mass of WOCE, which in itself has been found to be supportive of retention (Simon, 2011).

At the same time, institutions need to go beyond a deficit perspective in which outreach and recruitment goals are to increase numbers and improve WOCE's self-efficacy (Malcom & Malcom, 2011; Ong et al., 2018). Instead, they need to use these efforts as opportunities for institutional transformation, where both potential students and institutions learn from each other. For true transformation to occur, outreach and recruitment activities need to support a change in the image of who is expected to become an engineer so that WOC are actively welcomed and not simply sought as a means to achieve a representative number.

7.2 | Retention

The work of institutions and departments to bring WOC into engineering higher education does not end with outreach and recruitment; it continues throughout these students' education. The synthesis literature offers strategies for retention that, although they often overlap and have interlocking goals, we have classified here for easier reading.

7.2.1 | Hiring diverse faculty and staff, training for inclusion, and anti-discrimination policies

The literature demonstrates that diverse and thriving engineering departments strive to create and maintain an environment in which all students, including WOC, feel they belong and are welcomed (Alonso, 2015; Brown, 2008; Reyes, 2011; Vazquez-Akim, 2014). Departments should make intentional decisions to increase the numbers of faculty, administrators, and staff who are WOC, as their very presence and interactions with WOCE will be critical elements of WOC students' support systems (DeCuir-Gunby, Long-Mitchell, & Grant, 2009; Simon, 2011). The retention of WOC faculty, administrators, and staff is key to showing institutional commitment to change. This effort goes beyond having a few token WOC students and faculty (Kachchaf et al., 2015; Turner, González, & Wong, 2011). For this retention to be effective, institutions need to recognize, account for, and reward invisible work that is typically done by WOC faculty, such as mentoring students of color and representing both women and people of color on university committees (Kachchaf et al., 2015; Lucero, 2002, 2003; Turner, 2002). WOC faculty and staff are often burdened with these tasks in addition to their academic workloads, yet this work is usually not as valued for promotion and tenure as it should be. Retention of WOC faculty and staff in engineering can be improved by more holistic assessments and acknowledgment of their contributions.

Administrators also have a responsibility to provide training and resources to all departmental faculty and staff that equip them to support WOC (and other minoritized groups). In addition, faculty should seek training about classroom interactions to help ensure that WOCE are comfortable in class and in the department. Important training topics include (a) education about the crucial role of administrators in admitting and of faculty in graduating WOCE (Simon, 2011); (b) tools to help students who are struggling (Sosnowski, 2002); (c) training to address power dynamics and alleviate gender and racial bias in the classroom (Litzler et al., 2011); and (d) awareness about the familial and cultural responsibilities of WOC (Litzler et al., 2011; Reyes, 2011; Sharp, 2002). Administrators and faculty should take an

assets-based approach to interactions with WOCE, supported by deepening their own understanding of the strengths and types of capital that WOC bring with them (Samuelson & Litzler, 2016; Yosso, 2005). Additionally, policies against harassment and discrimination of any kind should be posted on the departmental website and in main offices. There should be clear and quick processes for addressing sexual harassment and discrimination (Gorman, 2014; also Corbett & Hill, 2015; National Academies of Sciences, Engineering, and Medicine, 2018). In summary, departmental cultures need to be transformed so that equitable policies and behaviors become the norm and transgressions are addressed in a swift and firm manner. It is important to note that WOCE should not be charged with the task of transforming the culture; rather it should be the responsibility of the institutions.

7.2.2 | Implementing formal and informal supports for WOCE

Since WOCE must expend so much time and energy on finding others like them and developing strong networks in order to strive for a sense of belonging in engineering (Brown, 2008; Gorman, 2014; Rice & Alfred, 2014; Shain, 2002), faculty and staff should provide formal and informal supports that facilitate these processes, thus reducing WOCE's resource expenditure. Successful formal supports have included professional development opportunities, such as internships and research opportunities for WOCE (Chowdhury & Chowdhury, 2007; Mitchell, 2014); mentoring (Jackson-Smith, 2015); experiential education through professional organizations (Reyes, 2011; Rice & Alfred, 2014); and other enrichment efforts beyond the typical summer bridge programs, such as a year-round, cohort-based model for students of color (Vazquez-Akim, 2014). Additionally, formal supports can extend to enabling the formation of and participation in professional counterspaces (Ong et al., 2018). For example, departments might fund student memberships to professional organizations and regularly pay for participation at conferences, such as the annual meetings of the National Society of Black Engineers (NSBE) or the Society of Women Engineers (SWE), where WOCE would likely see many others who look like themselves (Reyes, 2011; Rice & Alfred, 2014; also Ong et al., 2018).

Departments should consider hosting a chapter of NSBE, SWE, or the Society of Hispanic Professional Engineers on their campuses and encourage WOCE to take leadership roles (Sosnowski, 2002; also Ong et al., 2018). As a retention strategy, departments should offer opportunities for WOCE students to give back by mentoring younger college peers or by introducing engineering skills to students of color at a local high school (Alonso, 2015; DeCuir-Gunby et al., 2013; Mitchell, 2014; Trenor et al., 2008). Finally, faculty and staff should consider developing programs that are explicitly for WOC in STEM and, thus, consider their particular intersectional needs. The University at Buffalo's (UB) STEMInism group is one such example. Created in conjunction with the university's counseling services and led by a Black female staff member in the School of Engineering, the STEMInism group strives to support WOC students, faculty, and staff. The group, which meets biweekly, describes its goals as providing "a safe and supportive space for women of color in science, technology, engineering and mathematics fields to address concerns related to identity, psychosocial stressors, school-work-life balance and other factors, that may impact their academic functioning in undesirable ways" (University at Buffalo, n.d.). In addition, UB STEMInism offers participants professional development, mentoring, and social activities that enable WOC in STEM to support one another.

Administrators and faculty can also provide informal supports that enhance WOCE's sense of belonging. For example, staff in STEM departments might collaborate to provide WOCE with resources such as potential student allies or peer groups, or informal in-person or virtual forums where WOCE could discuss problems and successes (Alonso, 2015; Oden, 2003; Rice, 2011; Shain, 2002; Tate & Linn, 2005). Also, a department's offering of extracurricular opportunities, such as sports, artistic expression, cultural events, or community activism, can support positive mental health and increase a sense of belonging in engineering for WOCE (Sosnowski, 2002).

These formal and informal supports need to be integrated within the institutional fabric so that they truly transform the institutional expectations of how WOCE are to be treated. For WOCE, accessing these supports should no longer be perceived as a weakness, but as a strength signaling that they are being proactive in solving the difficulties they encounter.

7.2.3 | Altering the current organizational climate and creating a surrogate family in engineering

One of the key factors identified in the literature for increasing WOCE's retention is a sense of familial closeness in engineering programs that includes supportive relationships that go beyond the academic realm (Alonso, 2015;

Parker, 2013; Rice, 2011; Rice & Alfred, 2014; Vazquez-Akim, 2014). Most current engineering educational environments are experienced by WOCE as individualistic, isolating, competitive, and chilly (Alonso, 2012; Bush, 2013; Frillman et al., 2010; Parker, 2013) because they conform to the cultural norms of the White male majority. Thus, administrations and departments that implement policies and practices to encourage familial closeness could give themselves an advantage in retaining WOCE. Faculty are some of the professionals with whom WOCE interact the most through their studies. Therefore, their role in being supportive and providing a sense of belonging is fundamental. In addition to seeking training, faculty should develop mentoring relationships with WOCE and take part in activities with WOC students, both of which signal support through participation and presence. For example, the first author, Ong, documented the development of familial closeness during a multiyear evaluation of a biomedical engineering program for undergraduate students of color at a public institution. The program had implemented semiannual social outings for students and faculty that included bowling, game nights, picnics in the park, and a local boat cruise. One student commented, "All of the events, especially the cruise, greatly humanized the professors. That has really made them more approachable." Another stated, "The [game night] was really great. What I liked about it was that we're a small unit here [in the program] and you can interact with everyone else. Then, you go to take classes with them and you can have someone who you can identify with. ... So, it's a whole family feeling." Activities like these that facilitate approximating a sense of family also help students develop social capital by providing opportunities to network with peers, professors, and engineering professionals. Such opportunities should be tailored to the schedules of students who may be working or have other responsibilities (Trenor et al., 2008).

Department and administration staff can also be instrumental in keeping WOCE connected to their programs and in providing a "surrogate familial support system" (Rice, 2011, p. 202). This might look like department administrators who take time to know WOCE students' names and listen compassionately to their concerns, or financial aid and human resources staff who provide help and encouragement (Rice & Alfred, 2014). WOCE must have the sense that faculty and peers value their identities as WOC simultaneously with their engineering identities (Gorman, 2014) and support their academic, social, and intellectual identities (Tate & Linn, 2005). The formal and informal programmatic supports for WOCE detailed earlier should emphasize support for intersectional identities, the development of a sense of belonging and family, and the creation of stronger networks (Brown, 2000; Parker, 2013). Implementing these recommendations would likely increase departmental cohesion and morale and might, therefore, enhance the retention not just of WOCE but also of other students, particularly members of other minoritized groups such as women and students of color.

The types of supports, educational experiences, and engagements we have described here do not happen on their own, nor should WOCE be charged with implementing them. Institutions, departments, and faculty who understand the critical need for recruitment, retention, and advancement of WOCE must initiate and sustain them through policy implementation and systematic training efforts that are sensitive to gender and racial/ethnic differences of the populations that they intend to serve. Training and policy implementation should be reinforced by systems of accountability. Department and institutional leaders should provide consistent guidance to staff and faculty on how to integrate new learning into daily classroom practices and student interactions. By providing these supports, institutions of engineering can change their institutional culture to one where everyone belongs, enhance WOCE's self-efficacy, develop the types of capital that will benefit them moving forward, and advance a more diverse and innovative engineering student body and workforce.

8 | CONCLUSION AND RESEARCH RECOMMENDATIONS

In developing this synthesis, we observed two interrelated trends in the literature. On the one hand, the literature described how, without institutional support in the form of organized programs, the social settings in undergraduate education in engineering reproduced patterns of discrimination that perpetuate race and gender inequity through social interactions. Our analysis made evident these patterns of discrimination as the theme of social pain was prevalent in descriptions of feelings of isolation, incidents of stereotype threat, and experiences of harassment, to name a few. That these forms of social pain can be observed in literature produced within the last two decades indicates that larger historical inequities of power and privilege in U.S. culture—between White people and people of color, between men and women, and between those who fit "ideal norms" and those who live at the intersections of multiple identities—are still active in education environments, including in engineering higher education.

On the other hand, we found descriptions in the literature of organized environments, such as professional and student organizations, summer programs, and centers for women and/or students of color, providing surrogate familial systems to WOCE that included social and academic networks. Through participation in these programs, WOCE were more likely to succeed, and through these concerted efforts to support WOCE's success, institutions were able to circumvent and possibly start changing their cultural patterns of discrimination. From these contrasting but interrelated trends in the literature, we conclude that the path forward for institutions to retain more WOCE in undergraduate programs is to provide sustained institutional programs that explicitly buffer WOCE against ingrained patterns of social interaction that perpetuate discrimination and that seek to change institutional culture.

More research is necessary to unveil the reality and experiences of WOCE, to understand the impact and effectiveness of programs that target them, and to understand demographic trends around engineering education. Research should study the intersection of gender (including gender and sexual minorities), race/ethnicity, and engineering, including engineering subdisciplines, from different methodological and theoretical perspectives. For instance, areas to be examined through quantitative research include enrollment, persistence, and the differences among particular groups of students by race/ethnicity, gender, sexuality, class, path to engineering higher education, and other factors. Only a small number on such topics regarding WOCE have been published during the time frame of our study (Atwaters & Tao, 2015; Eng & Layne, 2002; Frehill, 2004; Leonard et al., 2013; Litzler et al., 2011; Lord et al., 2009, 2010; Lord & Camacho, 2013; Lord, Layton, & Ohland, 2011, 2014a, 2014b; Lord, Layton, Ohland, & Orr, 2013; Marra et al., 2009; Nelson & Brammer, 2010; Nelson & Rogers, 2003; Ohland et al., 2011; Ohland, Lord, & Layton, 2015; Ohland, Orr, Layton, Lord, & Long, 2012; Ohland, Orr, Lundy-Wagner, Veenstra, & Long, 2012; Orr, Lord, Layton, & Ohland, 2014; Ro & Loya, 2015; Trenor, Yu, Sha, Zerda, & Waight, 2007). Moreover, researchers should consistently collect and report data that are disaggregated by race/ethnicity and gender, paying particular attention to data about women in minoritized racial or ethnic groups (Leonard et al., 2013). Areas to be examined through qualitative research include WOCE's experiences in the intersection of race/ethnicity, gender, and their major (Lord et al., 2010). Researchers should also keep in mind the potential for mixed methods research to unveil findings inaccessible through a single methodological approach.

We consider that continued synthesis of relevant literature in this area should be part of a healthy research environment. We recommend that quality assessment of literature pieces be part of any literature synthesis to ensure that the works included are worth reading, citing, and considering when designing programs as recommended in earlier literature (Borrego et al., 2015).

As stated above, our searches for studies for this synthesis included WOCE in both higher education and careers. For the purpose of this article, we focused exclusively on undergraduate students. However, we found only a limited number of articles about WOC faculty and professionals in engineering (Berry, Farmer Cox, & Main, 2014; Bush, 2013; DeCuir-Gunby et al., 2009; DeCuir-Gunby et al., 2013; Lucero, 2003; Nelson & Brammer, 2010; Nelson & Rogers, 2003; Rice, 2011; Rice & Alfred, 2014; Simon, 2011; Somerville-Midgett, 2014; Tharp, 2002) and recommend that more research be conducted on this population. Even more limited was the literature on WOCE graduate students (Atwaters & Tao, 2015; Frehill, 2004; Morell, 2002; Oden, 2003; Ohland et al., 2012; Tran, Herrera, & Gasiewski, 2011), and we recommend more research on this population as well.

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APPENDIX: NOTABLE WORKS ON WOMEN OF COLOR IN ENGINEERING PUBLISHED APRIL 2015–OCTOBER 2019

The search phase of this project closed in March 2015, and studies on the experiences of women of color in engineering have continued to emerge. A selection of more recent studies for readers' further exploration is listed here.

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