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Sophie Pierszalowski for the degree of Doctor of Philosophy in Education presented on May 29, 2019.

Title: Undergraduate Research as a Tool to Promote Diversity, Equity, and Success in STEM: Exploring Potential Barriers and Solutions to Access for Students from Historically Underrepresented Groups.

Abstract approved:

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In response to concern over a lack of diversity in STEM postsecondary programs, institutions of higher education across the nation have promoted opportunities for undergraduate research. Such opportunities have been shown to enrich student experiences and success, especially for students from historically underrepresented groups. While these benefits have been fairly well studied, more research is needed to better understand how students from historically underrepresented racial/ethnic groups (Black/African American, Latin@, Native American/Alaska Native, and/or Pacific Islander/Native Hawaiian) come to interact with undergraduate research opportunities. In this dissertation, I present three manuscripts that collectively explore issues related to these students' access to opportunities for undergraduate research. In the first manuscript, I take a policy perspective to explore a wide range of institutional-level tactics and strategies intended to promote equity and inclusion in undergraduate research experiences. In doing so, I advance research-based recommendations toward increasing the success and persistence of students from groups historically underrepresented in postsecondary STEM, explicitly through involvement in

undergraduate research experiences. I highlight three guiding strategies for structuring institutional diversity action plans that have the potential to promote equitable access to undergraduate research experiences, and five specific tactics that institutional leaders will find attainable in relatively short time frames. I also offer a questionnaire for institutional self-assessment related to these tactics. In the second manuscript, I detail a systematic literature review that allows for a critical synthesis of the scholarship that has (and has not) been put forth toward understanding students' barriers to accessing undergraduate research. From review of relevant articles (n=18), I report a dearth of scholarship concerning issues of access specifically for students of color in STEM, as well as a limited use of theoretical/analytical frameworks employed, especially those that employed critical lenses to explore issues of access to undergraduate research. I present an extensive list of barriers to accessing undergraduate research experiences across disciplines and demographics that may serve as basis for robust future research concerning access to undergraduate research for students of color. In the third manuscript, I use semi-structured interviews with faculty members and STEM students of color in engineering to understand their experiences in facilitating and accessing undergraduate research, respectively. I document a wide range of potential barriers to accessing undergraduate research for engineering students of color, as well as for students from other historically underrepresented groups. While there was some overlap between faculty and student responses to questions about selection criteria and access to undergraduate research, I also diagnose an area of misalignment between student and faculty perspectives that may serve as an additional barrier to student access to undergraduate research: students' misguided perceptions about the importance of limited metrics of academic performance (e.g. high grades) towards securing participation in undergraduate research. Through the manuscripts outlined in this dissertation, I aim to bring attention to the differential access to undergraduate research experiences for all students that I argue represents a pressing, and largely unspoken, equity issue in higher education. I look forward to building on this work by continuing to offer viable solutions to key stakeholders at institutions of higher education, interrogating existing practices of student placement into undergraduate research experiences, and creating consciousness regarding equitable opportunities for experiential learning at institutions of higher education.

Undergraduate Research as a Tool to Promote Diversity, Equity, and Success in STEM: Exploring Potential Barriers and Solutions to Access for Students from Historically Underrepresented Groups

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Sophie Pierszalowski, Author

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CONTRIBUTION OF AUTHORS

Chapter 2 - Dr. Rican Vue contributed to the conceptualization, design, and writing of this manuscript and provided important policy-based insight around which to frame this work. Dr. Jana Bouwma-Gearhart contributed to the writing and editing of this manuscript.

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Chapter 4 - Dr. Jana Bouwma-Gearhart contributed to the design, analysis, and editing of this manuscript.

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CHAPTER 1 – Introduction

Motivations for the Research Study

The President's Council of Advisors on Science and Technology reported in 2012 that, to maintain its reputation for excellence in science and technology, the United States would require an additional one million STEM professionals over the next decade, equivalent to an increase of 34% each year of undergraduate STEM degree conferrals (President's Council of Advisors on Science and Technology, 2012). In addition to requiring a large quantity of STEM professionals, the U.S. will need to foster a STEM workforce that demonstrates excellence in order to meet the nation's evolving needs. Scholars have recognized that excellence and diversity in STEM are closely intertwined (Hong & Page, 2004; Page, 2008). In fact, increasing the representation and success of students of color in science, technology, engineering, and mathematics (STEM) career pathways has been a priority in the United States for decades (Hurtado, Newman, Tran, & Chang, 2010). However, despite having similar intentions to pursue a STEM degree upon entering college (Higher Education Research Institute, 2010), students that identify as Latin@, Black/African American, and American Indian/Alaska Native still remain underrepresented in U.S. science and engineering bachelor's degree programs when compared to their college-aged majority-group peers (National Science Foundation, 2018).

Promoting equity in the STEM disciplines is important for several reasons. First, people from diverse backgrounds tend to come with a wide range of problem-solving perspectives and strategies (Page, 2008). Thus, by encouraging the creation of diverse communities of researchers, we have the potential to counteract biases that limit scientific processes when research teams are homogenous (Intemann, 2009). This is especially important as our societal problems become more global and increasingly complex. By failing to consider and promote more means for equity in higher education contexts, we risk excluding those with high potential from the pool of future STEM practitioners. Indeed, many researchers and policymakers argue the lack of diversity in STEM poses a threat to global competitiveness and the national security of the U.S. (Hurtado, Cabrera, Lin, Arellano, & Espinosa, 2009; President's Council of Advisors on Science and Technology, 2012; Valla & Williams, 2012). As well, a lack of diversity in STEM has important social justice implications. By promoting diversity in STEM, we can ensure the "distribution of social goods attached to, and produced by, scientific practice and knowledge be equitable to all citizens, and not merely for the benefit of privileged groups" (Intemann, 2009, p. 250).

In response to concerns over a lack of diversity in STEM postsecondary programs, institutions of higher education across the U.S. have promoted a set of "high-impact practices" shown to enrich student experiences and success, especially for students from groups historically underrepresented in postsecondary institutions (Kuh, 2008). One of these high-impact practices is the faculty-mentored undergraduate research experience, wherein students engage in discipline-based inquiry in collaboration with faculty mentors. While student gains from participation in undergraduate research have been well documented for *all* students, a growing body of literature more specifically elucidates the positive effects of undergraduate research experiences for students from historically underrepresented groups. For example, Thiry and Laursen (2011) found that interactions with research mentors led to gains in confidence and a better understanding of educational and career possibilities for African American and Hispanic students. Other studies have reported that undergraduate research experiences provide opportunities to develop a science identity for women of color (Carlone & Johnson, 2007) and increase retention rates for African American and Hispanic students (Jones, Barlow, & Villarejo, 2010; Nagda, Gregerman, Jonides, von Hippel, & Lerner, 1998). In one investigation of an undergraduate research program designed for students historically underrepresented in STEM, participants (in comparison to non-participants) were shown to graduate faster with higher GPAs, were more likely to graduate with a science degree, and were more likely to enter a science graduate program (Slovacek, Whittinghill, Flenoury, & Wiseman, 2012).

While the benefits of undergraduate research experiences for students from underrepresented groups have been fairly well explored, more research is needed to better understand the ways in which students from historically underrepresented racial/ethnic groups (Black/African American, Latin@, Native American/Alaska Native, and/or Pacific Islander/Native Hawaiian) approach opportunities for undergraduate research. In order to maximally leverage the benefits of undergraduate research experiences to promote equity and diversity in STEM, we must first understand whether barriers exist that disproportionally effect students of color. I aim to fill this gap in our knowledge by exploring whether STEM students of color face any unique barriers to accessing opportunities to undergraduate research that may be related to barriers these students may face with regard to success and persistence in postsecondary STEM programs and experiences more generally (e.g. feelings of alienation from mainstream campus culture, as found in Feagin, Vera, and Nikitah (1996) or experiences with microaggressions, as found in Ong, Smith, & Ko (2017)).

Research questions

I present three manuscripts in this dissertation that collectively explore issues related to students' access to opportunities for undergraduate research. I address the following research questions within this dissertation:

1. *What strategies and tactics may strengthen institutional diversity action plans to promote more equitable access to undergraduate research experiences?*
2. *How might barriers to success and persistence in postsecondary STEM programs for students of color manifest as barriers to accessing opportunities for undergraduate research for the same population?*
3. *If barriers exist, what form(s) do they take that make it difficult for undergraduate engineering students of color to engage in research experiences?*

My first manuscript addresses the first research question from a policy perspective by clearly outlining research-supported approaches to promoting access and inclusion with regards to undergraduate research experiences. In doing so, I explore various institutional-level tactics and strategies that can be implemented as part of diversity action plans. In my second manuscript, I address the second question by presenting my systematic literature review exploring the work that has (and has not) been done toward understanding barriers to accessing undergraduate research for STEM students of color. In this manuscript, I hypothesize how general barriers in the way of success and persistence in postsecondary STEM programs for students of color (e.g. microaggressions, social exclusion) may get in the way of accessing undergraduate research experiences.

In my third manuscript, I address the third question in the context of undergraduate research within a College of Engineering at one four-year public university in the Northwest U.S. with a Carnegie classification of "highest research activity" (The Carnegie Classification of Institutions of Higher Education, 2019). I detail a qualitative study that explores specific barriers to accessing undergraduate research as they relate to relationships between faculty and students of color in engineering. I contend that this work challenges and supports scholars, practitioners, and leaders at institutions of higher education to focus more intently on issues of equity, inclusion, and access when attending to opportunities for undergraduate research. Finally, I look across all manuscripts to recommend strategies and tactics that can be put in place to promote more equitable access to undergraduate research experiences.

Theoretical frameworks, ontology, and epistemology

In my dissertation, I utilize frameworks of third generation Cultural-Historical Activity Theory (CHAT) and Critical Race Theory (CRT), to situate my research within issues of marginalization, power, race, culture, and history as they intersect with institutional structures, systems, and norms (Schwartz, 2012; Sólorzano & Yosso, 2002).

I use third-generation CHAT in my second manuscript to take a systems perspective (concerning access to undergraduate research) informed by multiple perspectives from a diversity of research subjects (Engström, 2009). CHAT affords me the ability to focus on the various *rules, community, divisions of labor,* and *mediating artifacts* that drive action of students, faculty members, and institutions within activity systems concerning accessing undergraduate research experiences. Ultimately, I use CHAT as a framework to identify and diagnose contradictions within and between activity systems with the subjects of students, faculty members and institutions. I argue these contradictions implicate areas for potential transformation at institutions of higher education, that may promote more equitable access to undergraduate research experiences for all students.

In my third manuscript, I use CRT as a framework to explore issues related to race, gender, class, sexuality, and bases for institutional and systemic racism that, per my research focus, may influence the educational experiences of students of color (Solórzano & Yosso, 2002). Employing CRT, I explore potential race-related barriers that may perpetuate differential access to undergraduate research, but that can go unnoticed through the use of other theoretical frameworks that reinforce dominant narratives about majority experiences (e.g. frameworks like communities of practice and legitimate peripheral participation that do not explicitly call attention to issues of access and inclusion in relation to power, privilege, and oppression). That is, CRT allows us to bring attention to social problems that may remain invisible or underexplored through other frameworks (Lincoln, Lynham, & Guba 2011). By using this framework, we can we begin to give voice to those whose who are historically underrepresented and promote positive social change that considers a more complete systems-perspective of relevant societal, cultural, and historical factors that influence a students' access to undergraduate research.

Operating from these two theoretical perspectives aligns with my personal ontological perspective that humans form their own subjective realities based on their experiences and interpretations of those experiences. Further, I recognize that human experiences, and their interpretations of them, are shaped by forces that dichotomize privilege and oppression in ways that can be influenced by race, ethnicity, gender identity, sexual orientation, ability, and socioeconomic status. My views align with those of Lincoln et al. (2011) who posit that within this navigation of privilege and power, our realities (and those of our research participants) are continually shaped by social, political, cultural, historical, economic, and situational contexts. These perspectives stand in contrast to a positivist ontology, one that assumes there is one objective and representative reality, and allows focus, instead, on the realities of those whose voices and experiences are differentially influenced by systems and structures of society (Solórzano & Yosso, 2002).

According to Gray (2017), reflexivity describes a scholars' consideration of their own belief systems and external influences and how those impact the ways they story themselves and the lives of others. I recognize that I am embedded in the scholarship outlined in this dissertation and, regardless of intentionally, my own identity, values, beliefs, and life experiences influence the way I interact with this research design, research participants, and data (Higgs, 2010). I adopt a subjectivist epistemological and ontological perspective, aligned with the theories outlined above, and recognize that my own reality is impossible to negate as I interpret the experiences of research participants. I acknowledge my identity as a first-generation college student and a white, female academic with five years of experience helping students of color access undergraduate research experiences while running the OSU STEM Leaders Program and the OSU Office of Undergraduate Research, Scholarship, and the Arts. As my experiences do not allow me to speak as an expert regarding the experiences of research participants (Duffy & Rigby, 2010), I am careful to present their experiences in their voices, and as informed by their checking ("member checking") of my presentation of their data.

Significance of the Dissertation

The three manuscripts in this dissertation are designed to complement one another. Ultimately, together, they represent original scholarship concerning undergraduate research as a tool to promote diversity, equity, and success in STEM and exploring potential barriers and solutions to access for students from historically underrepresented groups. I take a policy perspective in my first manuscript (published in March 2018 in the *Journal of STEM Education: Innovations and Research*) to explore a wide range of institutional-level tactics and strategies intended to promote equity and inclusion in undergraduate research experiences. In doing so, I advance research-based recommendations toward increasing the success and persistence of students from groups historically underrepresented in postsecondary STEM, explicitly through involvement in undergraduate research experiences. I highlight three guiding strategies for structuring institutional diversity action plans that have the potential to promote equitable access to undergraduate research experiences and five specific tactics that institutional leaders will find attainable in relatively short time frames. Finally, I offer a questionnaire for institutional self-assessment related to these tactics. I presented this work at the 2018 Professional and Organizational Development (POD) Network in Higher Education conference in Portland, OR on November 15th, 2018.

After completing this macro-level exploration, I wanted to focus more on the micro-level and explore specific barriers to accessing undergraduate research as they related to relationships between faculty and students. However, in order to better understand how to approach a more micro-level exploration of barriers to accessing undergraduate research experiences for students of color in STEM, I first needed to understand the extent of existing research that informs and explores this topic. Thus, my second manuscript details a systematic literature review that allows for a critical synthesis of the scholarship that has advanced, or failed to advance, our understanding of students' barriers to accessing undergraduate research. This analytical review makes an important contribution to the field by providing a summary that looks broadly across barriers to success and persistence in postsecondary STEM programs for students of color and, more specifically, at barriers to opportunity access for undergraduate research. It also points to an important gap in the literature that the study in my third manuscript (outlined below) aims to fill. From review of relevant articles (n=18), I report a dearth of scholarship concerning issues of access specifically for students of color in STEM, as well as a limited use of theoretical/analytical frameworks employed, especially those that employed critical lenses to explore issues of access to undergraduate research. I present an extensive list of barriers to accessing undergraduate research experiences across disciplines and demographics that may serve as a basis for robust future research concerning access to undergraduate research for students of color. Results from this manuscript were presented at the 2018 Association for the Study of Higher Education (ASHE) conference in Tampa, FL on November 16th, 2018.

In the third manuscript, I use semi-structured interviews with faculty members and STEM students of color in engineering at one postsecondary institution to understand their experiences in facilitating and accessing undergraduate research, respectively. I document a wide range of potential barriers to accessing undergraduate research for students of color, as well as for students from other historically underrepresented groups. While there was some overlap between faculty and student responses to questions about selection criteria and access to undergraduate research, I also diagnose an area of misalignment between student and faculty perspectives that may serve as an additional barrier to student access to undergraduate research: students' misguided perceptions about the importance of limited metrics of academic performance (e.g. high grades) towards securing participation in undergraduate research.

I see potential for dissemination of my dissertation work to a broad audience of stakeholders. It is my hope that the manuscripts presented in this dissertation will encourage educational researchers, educators and education leaders, and administrators to pay closer attention to the fact that undergraduate research experiences, widely recognized for their educational and professional affordances (Kinkel & Henke, 2006; Lopatto, 2007; Nagda et al., 1998; Slovacek et al., 2012), may be easier for some students to access than others.

Research on undergraduate research has most traditionally focused on student gains resulting from these experiences (e.g., Hunter et al., 2007; Lopatto, 2007; Russell, Hancock, & McCullough, 2007). While this work is important, especially in illuminating the strong, positive personal and professional gains for students from historically underrepresented groups (e.g., Nagda, Gregerman, Jonides, von Hippel, & Lerner, 1998; Slovacek et al., 2012), I contend that it does not pay sufficient attention to issues of access and inclusion. We must consider that when highlighting majority narratives about experiences with undergraduate research, we potentially undermine our ability to uphold the democratic ideals of education, ultimately presenting a serious equity concern (Solórzano & Yosso, 2016; Zamudio, Russell, Rios, & Bridgeman, 2011). This work makes an important contribution to a growing body of work that advances the field by more explicitly considering issues of access and inclusion and changing the focus from "*how* do students benefit from these experiences?" to "*who* is able to access and benefit from these experiences?"

Through the manuscripts outlined in this dissertation, I aim to bring attention to the differential access to undergraduate research experiences that I argue represents a pressing, and largely unspoken, equity issue in higher education that has viable solutions. Sustaining traditions in which there is differential access to undergraduate research and its benefits is inconsistent with our national narrative to promote inclusive excellence. I look forward to building on this work by continuing to offer viable solutions to key stakeholders at institutions of higher education, interrogating existing practices of student placement into undergraduate research experiences, and elevating consciousness regarding equitable opportunities for experiential learning.

CHAPTER 2 – Overcoming Barriers in Access to High-Quality Education After Matriculation: Promoting Strategies and Tactics for Engagement of Underrepresented Groups in Undergraduate Research via Institutional Diversity Action Plans

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Abstract

Considerable work is still required to eliminate disparities in postsecondary STEM persistence and success across student groups. Engagement in faculty-mentored research has been employed as one strategy to promote personal, professional, and academic gains for undergraduate students, although barriers exist that make it more difficult for some to participate than others. In this article, we highlight three guiding strategies for structuring institutional diversity action plans that will help ensure equitable access to undergraduate research experiences. Relevant to these three strategies, we propose five specific tactics that educators and institutional leaders will find attainable in relatively short time frames, in addition to a questionnaire for institutional self-assessment related to these tactics. By following the recommendations outlined in this article, and thereby establishing an infrastructure for equitable access to undergraduate research experiences, we assert that institutions can begin to close educational achievement gaps, meet growing U.S. workforce demands, and uphold the democratic ideals of higher education.

Introduction

In 2012, the President's Council of Advisors on Science and Technology reported that, in addition to maintaining our current rate of entry into STEM professions, the United States will require an additional one million STEM professionals over the next ten years to uphold the nation's reputation for excellence in science and technology. The Council recommended increasing the number of students receiving STEM undergraduate degrees by an annual rate of 34% to reach this goal (President's Council of Advisors on Science and Technology, 2012). Policymakers and researchers alike recognize that fostering excellence and promoting diversity in STEM fields go hand in hand (Hong & Page, 2004; Page, 2008) and prioritize an increase in the representation and success of students from groups traditionally underrepresented in STEM (Hurtado, Newman, Tran, & Chang, 2010), including students of color, students who are low income, women, and first-generation college students. Considerable work is still necessary towards building more diversity in STEM. In 2012-2013, only 16% (n = 290,000) of bachelor's degrees were awarded in STEM fields in the U.S. (National Center for Education Statistics, 2016). In 2012, students that identified as Hispanic, Black, and American Indian/Alaska Native remained underrepresented in U.S. science and engineering bachelor's degree programs when compared to their respective percentages of the national college-age population; that is, students that identified as Black, Hispanic, and American Indian/Alaska Native earned 8.8%, 10.3%, and 0.6% of science and engineering bachelor's degrees while they were 15%, 21%, and 0.9% of the college-age population, respectively (National Science Foundation, 2014).

National, state, and foundation initiatives (e.g., the Obama Administration's 2020 College Completion Goal [Kanter, Ochoa, Nassif, & Chong, 2011] and College Completion Toolkit [U.S. Department of Education, 2011], as well as Lumina's "big-goal" [Lumina Foundation, 2008]) have renewed attention in increasing college completion and prompted postsecondary institutions to develop strategies that will reduce disparities in persistence and enhance student success overall across student groups (Russell, 2011). Recent years have shown a proliferation of advocacy for the use of “high-impact practices” to help students, especially those from underrepresented groups, overcome barriers that obstruct student success and lead to attrition in STEM. High-impact practices, as defined by Kuh (2008), are largely equated with active learning practices (e.g., learning communities, service learning, first year seminars, study abroad, undergraduate research, and other forms of project-based learning). These practices are effective in promoting gains in GPA and persistence for all students because they demand a high degree of student involvement, allow for immediate feedback to students regarding their performance, encourage students’ interactions with diverse cultures and situations, and promote meaningful exchanges between students and faculty and peers over time (Adedokun et al., 2014; Clarke, Flaherty, Wright, & McMillen, 2009; Kuh, 2008; Morgan & Streb, 2001; Starke, Harth, & Sirianni, 2001). Although disproportionately large, positive effects have been documented for students from traditionally underrepresented groups who participate in high-impact practices when compared with majority students, historically underrepresented students (namely first-generation and African American students) have been less likely to engage in these practices than other groups (Kuh, 2008).

Despite progressive education reforms aimed at expanding postsecondary access (e.g., affirmative action and in-state tuition for undocumented students in select states), many students still struggle to gain equitable access to quality experiences after matriculating into a higher education institution. It is possible the disparity in involvement in high-impact practices is a result of social, academic, and structural barriers that exist for students underrepresented in postsecondary institutions. For example, Peréz Huber (2010) describes one first generation, low income student who was unable to apply for state- and federally-funded campus undergraduate research programs because of her undocumented status. This disparity in access may be exaggerated as students from traditionally underrepresented groups continue to find themselves entering a system designed for groups possessing most societal power (Rendón, Garcia, & Person, 2004). Social barriers also include racial and gender bias that create unwelcoming social climates in STEM and undermine identification with a STEM field (Carlone & Johnson, 2007; Ong, 2005). Moreover, first-generation college students' social positioning can limit their access to key information and resources important for securing opportunities to engage in high impact practices (Martin, Miller, & Simmons, 2014).

In addition, students of color sometimes face academic barriers in college that stem from the disparity in financial resources, high-quality curricula, computer/internet access, and availability of qualified teachers during their years in the pre-college educational system (May & Chubin, 2003). These factors indicate that academic barriers have more to do with the opportunity structure than academic potential. As such, this can become especially problematic when high impact learning experiences are distributed based on academic merit.

Indeed, both social and academic barriers are inextricably connected to structural issues (Hurtado, Alvarez, Guillermo-Wann, Cuellar, & Arellano, 2012; Smedley Myers, & Harrell, 1993). Among these structural concerns are institutional rewards that discourage faculty engagement with diversity (Tuckman, 1979) and the underrepresentation of faculty of color and women faculty in STEM (Towns, 2010), especially since faculty of color and women faculty more often provide support to underrepresented students (Schwartz, 2012). Another salient structural barrier is that tuition prices at four-year institutions in the U.S. have increased at a faster rate than student aid programs and median family income (Delaney, 2014; Perna & Finney, 2014), forcing many financially insecure students to work during college. This added time commitment can detract from a student's involvement on campus and inhibit opportunities to seek support from professors and peers outside of class (Foor, Walden, & Trytten, 2007). These are just a few examples from a long list of barriers that students from underrepresented groups face within higher education institutions that cause inequities in access to high impact practices.

With these considerations in mind, we frame this paper around the importance of equity when promoting access to undergraduate research experiences. First, let us make a clear distinction between practices that promote equity – intentionally redirecting resources to support and to alleviate institutionalized barriers that adversely impact groups of students who are historically underserved – and practices that promote equality - providing equal resources for all students. While the former practice attempts to close opportunity gaps that exist between groups of students, we contend that the latter allows disparities in access to opportunities to persist. An important distinction is that equity strategies are informed by a contextual understanding of inequities as shaped by a history of discrimination and exclusion (Bensimon, 2005). We call on a broad audience of policy makers and leaders in education and industry to enhance access to transformational postsecondary experiences for historically underserved students through equity strategies, to promote the redirection of resources to those who have historically been dispossessed of them in order to alleviate barriers and enhance access.

Institutional Diversity Action Plans to Support Access and Retention

Preventing underrepresented students from leaving higher education institutions is a major policy concern (Perna & Jones, 2013). Clewell and Ficklen (1986) note that, “from a policy perspective, the most important issue is not merely why [underrepresented] students drop out, but what can be done to prevent withdrawal” (p. i). The implementation of best practices for retaining students will look different across institutions, as each has its own set of priorities and challenges. While improving student success requires commitment from multiple stakeholders (e.g., federal, state, and institutional leaders, and policy makers; Perna & Jones, 2013), each college or university can work to address challenges and advance strategies for preventing attrition of students from traditionally underrepresented groups. The advancement of retention strategies is often attempted via formal university structures and related processes.

Iverson (2012) details structures and processes for advancing diversity-related strategies within postsecondary institutions. Campus officials may assemble a council to investigate issues associated with diversity (e.g. attrition of underrepresented students, discriminatory practices and policies). This diversity council may then produce official documents that are used to advance and guide policies for promoting an inclusive campus. These “diversity action plans” (p. 150) can provide a roadmap of strategies for promoting and supporting campus diversity and inclusion.

Unfortunately, diversity action plans and related initiatives have been criticized as ineffective towards building and sustaining inclusive campuses (Iverson, 2012), with some pointing to the existence of persistent inequalities as evidence that these plans have had little impact (Chang, 2002). Indeed, it seems that diversity action plans may primarily serve a symbolic role within intuitions (Clayton-Pedersen, Parker, Smith, Morena, & Teraguchi, 2007; Iverson, 2012), with little obvious impact on meaningful stakeholder action (Boyd, 1991). In an Association of American Colleges and Universities (AAC&U) report, Clayton-Pedersen et al. (2007) caution, "just having this commitment reflected in the mission is not enough to mobilize constituents to engage in comprehensive diversity work" (p. 26). If diversity action plans are to be effective, institutions must create the architecture for campus inclusivity through specific structures and strategies that can be implemented in realistic contexts.

Institutional Structures and Strategies

The potential success of institutional diversity action plans may lie in how well they sync with other strategies and structures on campus. Clewell and Ficklen (1986) investigated programs with various types of activities at four predominately white institutions that have been effective in retaining students from underrepresented groups to identify characteristics that have contributed to their success. Characteristics similar across these institutions included "the presence of a stated policy on minority enrollments; a high level of institutional commitment; a substantial degree of institutionalization of the program; comprehensiveness of services; dedicated staff; systematic collection of data, monitoring, and follow-up; strong faculty support; and non-stigmatization of participants" (p. i). They highlight the importance of marrying institutional policy with programs that support diversity towards creating effective retention efforts and offer a policy-driven model for developing effective retention programs for students underrepresented within postsecondary institutions.

In the model proposed by Clewell and Ficklen (1986), institutional leaders first make policy decisions to support enrollment and retention of underrepresented students. Second, institutional leaders outline a plan to implement this policy and generate a policy statement with enumerated goals. Third, they create, implement, and monitor a policy-driven retention program. Finally, they evaluate the retention program and use outcomes to inform future needs assessment. In this paper, we use this model as a framework for specific tactics concerning steps two and three towards retention of students from underrepresented groups. We begin by detailing a targeted review of literature concerning promoting postsecondary STEM success and persistence for students from underrepresented groups. We specifically advance ways to foster more equitable access to one specific, "high-impact" strategy, the undergraduate research experience, shown to be a practice of promise for gains in success and persistence for students from groups underrepresented in STEM who engage in them (Lopatto, 2010; Thiry & Laursen, 2011).

The Characteristics and Benefits of Undergraduate Research

While there may be different notions of what constitutes an undergraduate research experience, Laursen, Hunter, Seymour, Thiry, & Melton (2010) describe the model of undergraduate research experience that we adopt for this article, namely as having the following features: 1) students investigate an authentic research question that is specifically tailored to the student's ability, timeframe, and interests and is integrated into the area of interest of the faculty mentor; 2) the project continues across multiple weeks, is used as a teaching tool and exposes students to the challenges of research; 3) the student receives individualized mentoring by a professional role model; 4) the student becomes part of a research peer community; and 5) the student gets practice with scientific communication.

This definition, which is based on characteristic payoffs as well as the typical structures of such experiences, alludes to the benefits of such experiences documented in scholarly literature. Numerous scholars report that undergraduate research experiences lead to considerable personal, professional, and academic gains for students (Lopatto, 2003, 2007, 2010; Seymour, Hunter, Laursen, & DeAntoni, 2004; Zydney, Benett, Shahid, & Bauer, 2002). A growing body of literature more specifically elucidates the effect of these experiences for students from underrepresented groups. Thiry & Laursen (2011) found that interactions with research mentors led to gains in confidence and a better understanding of educational and career possibilities for African American and Hispanic students. Other studies have reported that undergraduate research experiences provide opportunities for developing a science identity for women of color (Carlone & Johnson, 2007) and increasing retention rates for African American and Hispanic students (Jones, Barlow,

& Villarejo, 2010; Nagda, Gregerman, Jonides, von Hippel, & Lerner, 1998). In one investigation of an undergraduate research program designed for students underrepresented in STEM, participants (in comparison to non-participants) were shown to graduate faster with higher GPAs, were more likely to graduate with a science degree, and to enter a science graduate program (Slovacek, Whittinghill, Flenoury, & Wiseman, 2012). Given the promise documented above, one might argue that such experiences should be available for all undergraduates, and especially those from groups underrepresented in STEM fields. Yet, significant social, academic, and structural barriers like those previously outlined above remain, preventing widespread participation in undergraduate research experiences.

Strategies and Institutional-Level Tactics to Promote Equitable Access to Undergraduate Research

Promoting equitable access to undergraduate research experiences requires a commitment to inclusive excellence that reaches every corner of a postsecondary institution (Clayton-Pedersen et al., 2007), including the bases and impacts of institutional diversity action plans. Informed by our targeted literature review, and based on our experience with programming meant to foster more equitable access to successful undergraduate research experiences, we highlight three guiding strategies for structuring institutional diversity action plans that will help ensure equitable access to undergraduate research experiences: faculty professional development, institutional programming for students, and curricular reform (Figure 1). Alongside an enhanced review of relevant scholarly literature, we now describe these strategies and propose a set of five tactics that we recommend as part of diversity action plans.

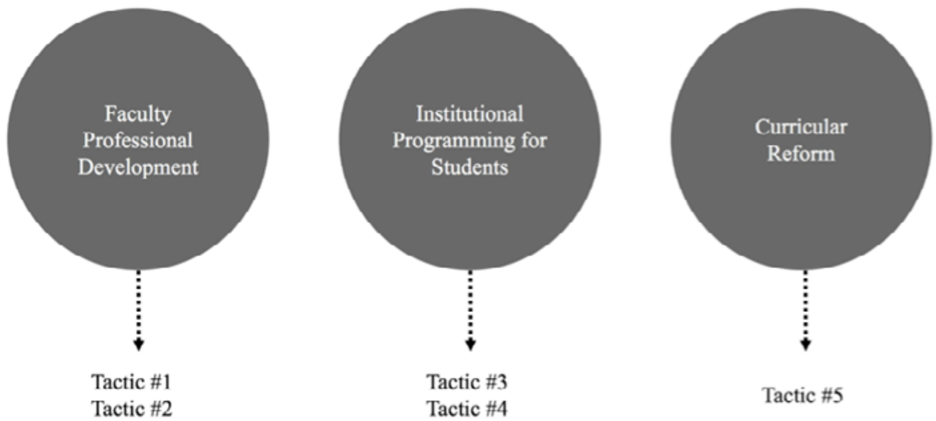

Figure 1. Three guiding strategies for tactics related to ensuring equitable access to undergraduate research experiences that we recommend should be part of institutional diversity action plans.

Faculty (and Future Faculty) Professional Development Towards Enhancing Commitment to Supporting Undergraduate Researchers from Underrepresented Groups

Without a commitment from well-educated faculty, ensuring equitable access to undergraduate research is very unlikely. Faculty are the gatekeepers to these opportunities and shape a student's experience while engaging in undergraduate research (Campbell & Skoog, 2008; Zydney et al., 2002). Expanding access to undergraduate research experiences requires educating individual faculty about the impacts of traditional selection criteria and cultural competency as it relates to research.

Tactic #1: Create programming and incentives for research faculty to learn about and utilize more holistic measures of selection criteria when accepting undergraduate researchers.

Many undergraduate research programs, based largely on the decisions of individual professors overseeing student experiences, select undergraduate researchers from applicants with strong grades in their college-level coursework (Laursen et al., 2010; Slovacek et al., 2012). However, personal, institutional, and societal barriers exist that can negatively impact the academic performance of underrepresented students in STEM (e.g. Martin et al., 2014). Thus, a method of selection based primarily on grades reduces opportunities for students who are struggling academically to participate in experiences that could lead to positive outcomes, including gains in academic performance. Unfortunately, faculty offering and supporting undergraduate research are often faced with institutional pressures to publish and secure external funding and prefer students who they believe can best help advance their agendas.

We recommend two related approaches for incentivizing research faculty to embrace a more holistic conception of merit when selecting undergraduate researchers to join their groups, considering traits like interests, drive, and commitment to learning. This may require a change in mindset to one that considers undergraduate research as a tool for cultivating opportunity and merit, rather than serve as a sorting mechanism that rewards those who already possess historic access and academic traits and, thus, are presumed to require little training (Gunier, 2015). Research faculty may be more likely to support diversity with institutional recognition. Towards this, institutions can change promotion and tenure guidelines so they reward faculty commitment to supporting diversity, a concept often overshadowed by the importance of research advances when tenure decisions are made (Tuckman, 1979). Second, given the importance of faculty mentoring on the success of students of color in STEM (Griffin, Perez, Holmes, & Mayo, 2010), institutions can instate prestigious awards for excellence in mentoring and the demonstration of a commitment to promoting diversity.

Tactic #2: Require cultural competency, biases, and diversity training for faculty, postdoctoral researchers, and graduate students who engage with undergraduate researchers.

Students from groups underrepresented in STEM may face cultural and institutional barriers to success even after joining a research group and institutional agents may perpetuate a culturally insensitive environment. While all students experience pressures and stress (e.g., academic demands) when acclimating to a new learning environment, students of color experience additional stresses (e.g., social climate stress—limited number of faculty and students of color, low expectations and negative treatment from white faculty and peers, etc.; interracial stress—trying to maintain ethnic/racial identity, etc.; racism and discrimination—stereotyping, etc.) related to their social status that adversely impact their academic performance (Smedley et al., 1993). Thus, students from groups underrepresented in STEM may experience more difficult transitions into research experiences as a result of additional stresses. For example, Ong (2005) found that young women of color were required to do a considerable amount of added work to learn the unspoken rules of the physics culture and become accepted by male faculty and peers. Another study followed the experiences of a Native American female student and found that the lab coordinator, department chair, and dean of the college were all insensitive to her concerns about dissecting mice which required committing cultural taboos regarding dead bodies (Carlone & Johnson, 2007). Thiry and Laursen (2011) warn that “research mentors of undergraduate students should be aware of the dual scientific and educational aspects of their advising role and its significance in shaping students’ identities and career trajectories” (p. 1).

Towards this, we recommend an institutional policy that all STEM faculty, postdoctoral researchers, and graduate students (two future faculty groups who often work alongside faculty in their engagement with undergraduate researchers) complete a training on cultural competencies, implicit and explicit biases, and the value of diversity in all corners of campus. Our recommendation is one promoted by others, including the AAC&U, which has urged postsecondary institutions to provide professional development opportunities for faculty to learn how to best support students from underrepresented groups (Clayton-Pedersen et al., 2007). We encourage that institutions learn from others already attempting such tactics, such as California State University at Fresno that has established a faculty development program aimed at better supporting students from underrepresented groups (Clewell & Ficklen, 1986). An organized undergraduate research program, in fact, may allow relatively easy implementation of, and motivation for, faculty professional development of such focus. Program organizers could require that the training is completed prior to the start of the program and is necessary to receive research development funds to support the work of the student.

Institutional Financial and Programming Support for Underrepresented Students to Participate and Succeed in Undergraduate Research Experiences

Many institutions rely on external grant-funded support for programs that promote success of students from diverse backgrounds. However, without institutionalization, these programs often only last a few years and their benefits only reach students who matriculated during the years the grant was awarded. Institutional funding devoted to programming for students from underrepresented groups is necessary to meet long-term diversity goals.

Tactic #3: Provide institutional funding for sustained undergraduate research programs that provide paid research experiences for students underrepresented in STEM.

Students from low-income backgrounds often work while enrolled in school to pay for their education (Foor et al., 2007). Moreover, students from underrepresented groups are often more concerned with their ability to pay for college than students of European descent (Hurtado et al., 2007). These added pressures and work commitments mean students are excluded from important social, professional, and academic campus community-building events that take place outside of the classroom (Foor et al., 2007; Fournier & Bond, 2015), including undergraduate research experiences.

Institutions can encourage students from low-income backgrounds to stay engaged on college campuses by providing sustained funding for undergraduate research programs that offer paid research experiences. Several programs like this have already been established across the U.S., including the Minority Opportunities in Research (MORE) programs, which provide financial incentives for students from underrepresented groups who engage in undergraduate research (Slovacek et al., 2012). However, many programs similar to MORE are primarily funded through federal and state granting agencies and lack institutional support, meaning they may only last a few years. A commitment to diversity requires institutionalizing programs that demonstrate their effectiveness in promoting the success and retention of students from groups traditionally underrepresented in STEM.

Tactic #4: Offer free preparatory programming regarding undergraduate research experiences for students underrepresented in STEM

Some students lack necessary coaching on why and how to seek an undergraduate research experience. Unlike some continuing-generation students, first-generation students may not realize the significance of undergraduate research when they enter college (Pascarella, Pierson, Wolniak, & Terenzini, 2004) and their parents may be unaware that undergraduate research often serves as a pathway to graduate school (Slovacek et al., 2012). Additionally, to secure an undergraduate research opportunity, a student must know how to identify a faculty mentor to work with, contact and meet the faculty mentor face-to face, and make a strong argument for why they are interested in research. This practice may be more daunting for first-generation students, who sometimes encounter more difficulty locating support and resources for navigating university processes (Martin et al., 2014). In particular, first generation college students must exert additional effort to acquire the similar types of resources readily available to continuing generation students through their immediate networks. Due to this disparity in key forms of social and cultural capital, continuing-generation students have greater access to undergraduate research experiences than first-generation students.

In a review of undergraduate programs that were successful in retaining students from underrepresented groups, Clewell and Ficklen (1986) highlight orientation programming as a critical component of success. Schneider et al. (2016) echo the importance of “pre-research” programming in their analysis of three different pre-research course models. The authors found that over 50% of students who participated in a pre-research course were involved in undergraduate research one year after taking the course and over 75% of students were involved two years after taking the course. Eighty percent of students who became involved in research after the course felt that it prepared them for participation in research and 74% felt that it made them a better candidate for research experience.

Thus, we recommend that institutions offer workshops or classes that serve as an orientation to undergraduate research experiences in order to demystify the processes involved in securing and succeeding in undergraduate research. This curriculum should include understanding the benefits of undergraduate research, identifying professors to work with, and utilizing best practices for approaching and communicating with faculty. It should also address the norms and expectations within research environments, including what to expect in research group meetings, how to keep a detailed lab notebook, and how to read peer-reviewed literature. This programming may also be intentionally structured to cultivate a network of support among participants and institutional agents that can be accessed to navigate undergraduate research opportunities and experiences upon completion of the workshop or course. This offering should be available to any student who would benefit and should be free to avoid the added financial pressure of enrolling.

Curricular Reform to Enhance Research Experiences Across Undergraduate Programming

Classroom instruction is the cornerstone of our higher education institutions. Because each student has access to learning experiences within the classroom, institutions can integrate opportunities for engagement in research-based learning within these regularly attended educational settings.

Tactic #5: Integrate undergraduate research experiences into the classroom.

As students from underrepresented groups face barriers that could affect their ability to access an undergraduate research experience, including a lack of social and cultural capital, financial constraints, an absence of culturally relevant role models, and inadequate academic preparation (Foor et al., 2007; Martin et al., 2014; May & Chubin, 2003; Tsui, 2007), we also recommend that institutions build undergraduate research experiences within the courses in which students are already engaged. Wei and Woodin (2011) highlight several innovative approaches to integrating research into a biology curriculum and found that students reported benefits, including increased interest in science, increased confidence in scientific skills, and an enhanced understanding of the scientific process.

Integrating research into classroom learning is especially important for students with no prior exposure to undergraduate research or who are unaware of what research entails and the gains associated with involvement in undergraduate research specifically. In this case, a student will reap some of the benefits of undergraduate research through in-class, high-impact learning and may be predisposed to seek out additional opportunities they might not otherwise have. Additionally, because many students are unable to engage in undergraduate research because they work long hours outside of class time (Foor et al., 2007), this tactic allows students to derive the benefits of the experience without having to devote valuable out-of-class time. Ultimately, this tactic has the potential to impact all students and not just those traditionally underrepresented in STEM.

Institutional Self-Assessment

Each of the tactics outlined above serves to address an underlying equity concern within postsecondary education. Table 1 provides a list of questions that institutional leaders can ask when assessing whether, and to what extent, these concerns are being attended to at their institutions and, relatedly, to what extent they are promoted/stipulated by their institutional diversity action plans. Given these considerations, leaders can make decisions about how diversity action plans should be revised and where enhanced equity efforts should be focused.

Table 1

General Equity Concerns Related to Accessing Undergraduate Research and Specific Considerations for Each Tactic Proposed

Tactic	General Equity Concern	Specific Considerations Related to Proposed Tactic
1	Are faculty encouraged to embrace a holistic, democratic conception of merit when selecting students?	• How can we improve promotion and tenure guidelines to recognize commitment to diversity? • Can we put awards in place that recognize excellence in mentoring and a commitment to diversity?
2	Do all members of a research group know how to best support students from underrepresented groups?	• What type of training is available to promote cultural competency? How can this be improved? • How can faculty be motivated to engage?
3	Are those who must work to stay in school excluded from research opportunities?	• To what extent are opportunities available for paid undergraduate research experiences and how can this be improved?
4	Do all students know why/how to engage in undergraduate research?	• To what extent are free preparatory workshops or courses offered for those who need additional help getting involved in undergraduate research? How can this be improved?
5	Are there opportunities for research for those who are unaware of the benefits of engaging in it and/or those who have commitments that prevent them from taking part in opportunities outside of coursework?	• To what extent have undergraduate research opportunities been integrated into the curriculum? How can this be improved?

Trade-Offs and Related Considerations

Like most new initiatives, and associated strategies and tactics, there will be trade-offs. This is especially true as postsecondary institutions, and their college and department units, continue to attend to a greater diversity of student needs and strive for programming that is relevant to modern society and workforce needs, all the while feeling ever more squeezed financially. As always, it is savvy to consider where resources might be diverted from and to design creative approaches for minimizing costs associated with new initiatives. Such consideration may also guard against the disconnect of espoused goals and strategies stipulated in institutional diversity action plans and stakeholder actions. We now turn to exploring these issues in relation to the recommended strategies and tactics above.

The costs associated with creating incentives for research faculty to utilize more holistic measures of selection criteria when accepting undergraduates into the group (Tactic #1) are difficult to elucidate. The adjustment of promotion and tenure guidelines is likely to implicate extensive administrative time and effort, more so than financial investment. The creation of a prestigious award for excellence in mentoring could be a relatively quick, inexpensive alternative. However, an award would have much less impact on institutional change than the adjustment of promotion and tenure guidelines, which should be considered in the context of an institution's diversity action plan.

While there are no immediate costs to professors associated with employing more holistic measures of selection criteria, institutions should consider the role that this first tactic will have on a professor's ability to maintain a competitive research agenda. Mentoring students can be time-consuming for faculty; however, mentoring can be a communal effort that involves graduate students, senior undergraduates, and post-doctoral researchers. Graduate students can themselves derive benefits from mentoring others (Feldman, Divoll, & Rogan-Klyve, 2013; Reddick, Griffin, Cherwitz, Cérda-Pražák, & Bunch, 2012). These benefits include deeper understanding of themselves and their discipline, professional development as future teachers, contribution to diversifying the field, and greater awareness of the reciprocal nature of mentoring that involves viewing the ability to pass on knowledge gained from past mentoring relationships as a benefit (Reddick et al., 2012). Thus, mentoring can become less onerous and potentially have the added benefit of creating a more cooperative and inclusive culture in STEM. That being said, institutions should be attentive to an equitable distribution of mentoring since faculty of color and women faculty tend to take on much of these commitments (Guarino & Borden, 2016; Umbach, 2006). Despite the emotional, professional and financial costs that can come with engagement with undergraduate research, faculty of color's investment in students is motivated by a desire to counter the general disregard and mistreatment of students of color among the larger faculty body (Schwartz, 2012).

Finally, it is worth noting that effective research mentoring can yield benefits for mentors that are often overlooked, including research productivity and professional development (Morrison-Beedy, Aronowitz, Dyne, & Mkandawire, 2001). Morrison-Beedy et al. (2001) make the important point that "the professional successes for the faculty mentor ultimately become successes for the college and university, as well as contributes to the scientific advancement of the… profession" (p. 296). Thus, emphasizing potential gains from mentoring may help encourage broader faculty participation.

The cost of requiring a training for professors who engage with undergraduate researchers (Tactic #2) would be minimal and, assuming it is offered in an online-format, only includes the cost of creating the training. The materials/resources needed to create this training could be borrowed from existing professional development opportunities at the institution (e.g. social justice trainings). Providing paid research opportunities for students underrepresented in STEM, including low income students (Tactic #3), will be the most expensive tactic to implement. Of course, the cost will vary depending on the size of the institution and the number of undergraduate researchers the intuition is willing to support. These decisions will have to be made on a case-by-case basis. One way to reduce cost to the institution would be to encourage the use of work-study hours for eligible students within the program. However, an active commitment to campus inclusion ultimately requires devoted funds towards equitable access to high-impact practices.

Offering free research preparatory workshops or courses (Tactic #4) could only include the cost of the instructor. Many higher education institutions already house an office of undergraduate research that would be an ideal entity to take responsibility for this offering. Integrating undergraduate research into the classroom (Tactic #5) will be time and resource-consuming for faculty. However, faculty can seek guidance from education-based units, such as institutional centers for teaching and learning. This course transition could also become the independent study work of a graduate student that would yield experience with curriculum design/redesign. To incentivize this important transition, institutions could provide small curriculum re-design grants to professors willing to make these changes.

Although expanding research opportunities may potentially require additional time dedicated to guidance and mentoring, we encourage institutions to consider the important trade-offs of focusing on teaching over research. According to Perna and Finney (2014), “When public resources are finite, pursuing research excellence may come at the expense of other statewide goals, particularly statewide efforts to promote the overall educational attainment of its population and to reduce gaps in attainment across groups" (p. 22). Rather than sacrifice research excellence to focus on student success, we propose focusing on both at the same time. Undergraduate research allows professors to maintain their research focus while contributing to student success in the capacity that most know best. Increasingly, student retention and persistence has become a barometer of institutional quality and prestige (Volkwein & Sweitzer, 2006). Reducing disparities also addresses government demands for improved performance. Thus, such outcomes can advance the school's reputation for inclusive excellence and for fostering a culture of undergraduate research success for all students.

Conclusion

The proposed strategies and tactics offered above represent research-based recommendations towards increasing the success and persistence of students from groups traditionally underrepresented in postsecondary STEM, explicitly through involvement in undergraduate research experiences. We think our recommendations are particularly timely as educational opportunity gaps persist while societal issues we face continue to grow in scope and complexity. Beyond increasing retention for students from underrepresented groups (Nagda et al., 1998), the diversity-related outcomes resulting from these tactics should extend beyond the institution to benefit the greater U.S. society in two important ways. First, these tactics would contribute to the U.S. goal of producing additional STEM professionals to meet our workforce demand, boosting our economy, and maintaining our reputation of excellence in science and technology (President's Council of Advisors on Science and Technology, 2012). This is closely tied to enhancing our ability to address complex societal problems, which require effectively leveraging the talents and capabilities of individuals from diverse backgrounds (Hong & Page, 2004; Page, 2008). Second, increasing educational attainment would save individuals, state and federal governments, and society a considerable amount of resources that are lost when students leave higher education institutions before graduating (Perna & Finney, 2014).

We assert that such explicit strategies and tactics should be part of institutional diversity action plans. In her policy analysis, Iverson (2012) found that institutional diversity action plans expressed the need to "identify obstacles and barriers to full participation in the academic, cultural, and social life of the university" (p. 159). Beyond enumerating such barriers, institutions must outline concrete, tractable tactics that create sustainable change by eliminating these barriers. This paper looks at one high-impact practice that can be leveraged to close achievement gaps for students by providing equitable access to involvement in a type of experiential learning has been shown to lead to gains in academic, personal, and professional performance. By following the tactics outlined above, we assert that institutions can begin to close educational achievement gaps and uphold the democratic ideals of higher education. In addition to nurturing the capacity of students of color to reach their full potential, the intentional cultivation of inclusion within STEM education is an investment poised to have societal benefits. These efforts will in turn help us build a stronger STEM U.S. workforce and promote heightened STEM literacy among our populace.

CHAPTER 3 – Barriers to Accessing Undergraduate Research for STEM Students of Color: A Systematic Review

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Introduction

In 2012, the President's Council of Advisors on Science and Technology reported that the United States would require an additional one million STEM professionals over the next decade to maintain its reputation for excellence in science and technology, equivalent to an increase of 34% each year of undergraduate STEM degree conferrals (President's Council of Advisors on Science and Technology, 2012). In addition to requiring a large quantity of STEM professionals, the U.S. will need to foster a STEM workforce that demonstrates excellence in order to meet the nation's evolving needs (e.g., increasingly complex socioscientific problems implicate the need for interdisciplinary work). Scholars have recognized that prominence and diversity in STEM are closely intertwined (Hong & Page, 2004; Page, 2008), and increasing the representation and success of students of color in science, technology, engineering, and mathematics (STEM) career pathways has been a priority in the United States for decades (Hurtado, Newman, Tran, & Chang, 2010). Yet students that identify as Latin@, Black/African American, and American Indian/Alaska Native remain underrepresented in U.S. science and engineering bachelor's degree programs when compared to their college-aged majority-group peers (National Science Foundation, 2018).

The heightened sense of competition, large class sizes, and limited student-faculty interactions in postsecondary science and engineering programs make it challenging for many students to complete a STEM degree, regardless of race or ethnicity (Baldwin, 2009). However, for students of color, race/ethnicity-related barriers may introduce additional challenges. For example, research has shown that students from historically underrepresented racial/ethnic groups in STEM experience stereotype threat, or anxiety that arises when one expects to be evaluated based on negative stereotypes, more strongly than students identifying as white; such stereotype threat has a positive, significant effect on likelihood of attrition from postsecondary STEM programs (Beasley & Fischer, 2012). Research has also shown that higher rates of graduation were associated with African American engineering students' lower perceptions of discrimination and racism, after controlling for institutional category (Brown, Morning, & Watkins, 2005). Other studies have introduced the notion that the intersectionality of multiple historically underrepresented identities means students of color who are also women, first-generation college students, low-income students, or students identifying as LGTBQ+ must navigate multiple systems of oppression simultaneously (Ong, Wright, Espinosa, & Orfield, 2011). For example, in a longitudinal study of women of color in physics, Ong (2005) found that participants had to engage in a considerable amount of added social and psychological work to persevere in physics undergraduate and graduate programs through strategies such as "passing", which is described as enacting false social identities.

In response to concern over a lack of diversity in STEM postsecondary programs, institutions of higher education across the nation have promoted a set of "high-impact practices," shown to enrich student experiences and success, especially for students from groups historically underrepresented in postsecondary institutions (Kuh, 2008). One of these high-impact practices is the faculty-mentored undergraduate research experience, wherein students engage in discipline-based inquiry/research/scholarship activities in collaboration with expert faculty mentors. Undergraduate research experiences can take many forms (see a recent NASEM (2017) report on the successes, opportunities, and challenges of undergraduate research experiences for STEM students highlighting eight different forms). Two of the most common types are apprentice-style research experiences and course-based undergraduate research experiences (CUREs), which are the focus of this analysis.

Within the apprentice-style model of undergraduate research, a student (or small group of students) works closely with an experienced faculty mentor to investigate outside the classroom a question(s) appropriate and meaningful to a discipline. Many studies have pointed to student gains resulting from this type of student-faculty partnership. For example, Hunter, Laursen, and Seymour (2007), via an ethnographic study of students and faculty engaging in a summer apprentice-style research program, found that both mentors and mentees felt that participation in the program helped students learn to work and think like scientists, e.g. through the development of problem solving skills and by gaining a better understanding of the nature of scientific knowledge. Students engaging in CUREs, in comparison, also explore novel and appropriate disciplinary questions and make intellectual contributions to their field, yet work done in the context of CUREs typically requires more step-by-step guidance from a course instructor when compared to an apprentice-style model (NASEM, 2017). Recently, scholars have begun to recognize the power of CUREs towards making undergraduate research experiences more accessible and inclusive because coursework is already an integral part of a students' experience in higher education (Bangera & Brownell, 2014; Pierszalowski, Vue, & Bouwma-Gearhart, 2018).

A growing body of literature elucidates the positive effects of undergraduate research experiences specifically for students from historically underrepresented groups. For instance, interactions with research mentors can lead to gains in confidence and a better understanding of educational and career possibilities for African American and Hispanic students in STEM (Thiry & Laursen, 2011). Other studies have reported that undergraduate research experiences provide opportunities to develop a science identity for women of color (Carlone & Johnson, 2007) and increase retention rates for African American and Hispanic students (Jones, Barlow, & Villarejo, 2010; Nagda, Gregerman, Jonides, von Hippel, & Lerner 1998). In one investigation of an undergraduate research program designed for students historically underrepresented in STEM, participants graduated faster and with higher GPAs, were more likely to graduate with a science degree, and were more likely to enter a science graduate program when compared with a propensity score matched comparison group (Slovacek, Whittinghill, Flenoury, & Wiseman, 2012). In response to these findings, federal agencies like the National Science Foundation and the National Institutes of Health have committed significant funding to increase the number of undergraduate research opportunities, with the ultimate aim of fostering racial/ethnic diversity in STEM and the nation’s capacity for research innovation and technological advancements (Eagan et al., 2013).

While the benefits of undergraduate research experiences for underrepresented student groups have been fairly well explored, more research is needed to better understand how students from historically underrepresented racial/ethnic groups (Black/African American, Latin@, Native American/Alaska Native, and/or Pacific Islander/Native Hawaiian) come to interact with undergraduate research experiences. Specifically, in this article, we explore issues of access for students of color related to opportunities for undergraduate research, considering how similar barriers for students' of color success and persistence in postsecondary STEM programs and experiences, overall, may manifest as barriers to accessing the undergraduate research experiences argued to help reduce these barriers. Consider:

> Lola, a female student of color studying engineering at a predominately white institution, regularly confronts microaggressions and feelings of racial/ethnic isolation in her field, barriers shown to negatively affect her success in STEM (see Ong, Smith, & Ko, 2017). Realizing this student would likely yield large personal and professional gains from engaging in undergraduate research experiences, a supportive advisor encourages her to "join a research lab."

Yet, might the barriers impacting Lola's success in STEM in some way manifest as barriers in accessing a research experience? For example, might Lola's feelings of alienation from mainstream campus culture, as illuminated by Feagin, Vera, and Nikitah (1996) in their study of African American students' experiences at a predominately white university, cause this Lola to intentionally distance herself from extracurricular work or interactions with faculty or other researchers?

We contend there are important reasons to explore issues of access to undergraduate research for students of color at this moment in time. First, if barriers to participation in undergraduate research are found, stakeholders may be able to act on the continued disparities in persistence and retention in postsecondary STEM education because undergraduate research experiences have been shown to lead to gains both. Such knowledge may help inspire additional work and affordances to help ensure students of color have equitable (i.e., as opposed to equal) access to opportunities like undergraduate research and the benefits these experiences may reap (Pierszalowski et al., 2018). Second, research on undergraduate research has most traditionally focused on student gains resulting from these experiences (e.g., Hunter et al., 2007; Lopatto, 2007; Russell, Hancock, & McCullough, 2007). While this work is important, especially in illuminating the strong, positive personal and professional gains for students from historically underrepresented groups (e.g., Nagda et al., 1998; Slovacek et al., 2012), we argue that it does not pay sufficient attention to issues of access and inclusion. We must consider that when highlighting majority narratives about experiences with undergraduate research, we potentially undermine our ability to uphold the democratic ideals of education, ultimately presenting a serious equity concern (Solórzano & Yosso, 2016; Zamudio et al., 2011). Thus, we contribute to a growing body of work that advances the field by more obviously considering issues of access and inclusion and moving the focus from "*how* do students benefit from these experiences?" to "*who* is able to access and benefit from these experiences?"

The goals of this paper are threefold. First, we summarize barriers to success that students of color face in relation to STEM programming at the postsecondary level using a non-structured review of recent literature. Building from this initial review, we report on a structured review of the literature that then examines barriers to accessing undergraduate research for STEM students of color and, ultimately, for all students. We analyze our findings through the lens of Cultural-Historical Activity Theory (CHAT) and discuss implications of the relative current lack of focus on access to undergraduate research at postsecondary institutions. As part of this discussion, we pose a collection of hypotheses for how barriers in the way of success and persistence in postsecondary STEM may manifest as barriers to accessing undergraduate research experiences for students of color, with the hope of guiding future consideration and action, on the part of researchers and practitioners.

Theoretical Framework

We employ Cultural-Historical Activity Theory (CHAT) as a theoretical framework to situate our findings. This decision arose during analysis of our structured literature review, from our observation that barriers to accessing undergraduate research experiences generally were with respect to three various interrelated entities in a complex system of interactions (i.e., students, faculty, and institutions) and the influences they recognize and contribute to with respect to undergraduate research experiences. In this study, we define a system as a collection of entities that are influencing and interacting with undergraduate research experiences.

CHAT was first proposed by psychologist Lev Vygotsky to demonstrate that all human action is mediated, and that the relationship between actions and what mediates them is influenced by the social context in which it takes place (Vygotsky, 1978). For instance, the behavior of a teacher is influenced by many mediating factors which are shaped by society, including her school's rules and norms, standardized testing, the interests of her students, and cultural expectations of what it means to be a teacher. A second generation of CHAT focused more on the individual within a larger system of collective activity involving multiple other individuals (Leont'ev, 1978), such as an educator whose actions are partially influenced by colleagues, administrators, students, and students' families. We utilize third generation CHAT, which was developed by Yrjö Engeström to address additional challenges related to the interconnectedness of multiple activity systems and the diverse perspectives reflected by them (Engeström, 2001), allowing for exploration of joint activity between multiple, interrelated systems, for instance those of the educator, the student's family, and parent-teacher association.

According to Engeström (2001, 2009), each activity system consists of a *subject*, *object*, *mediating artifacts, rules, community*, and *division of labor* (Figure 1).

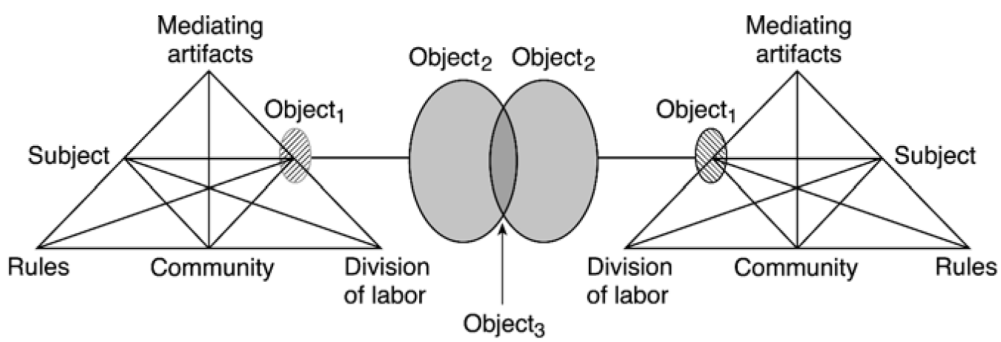

Figure 1. Two interacting activity systems which serve as a basis for third generation activity theory (from Engeström, 2001).

The *subject* of an activity system (e.g. a student) is the individual or group of individuals that are collectively moving toward an *object*, or an outcome that motivates activity (e.g. graduating in a STEM major). In third generation CHAT, multiple interacting activity systems have their own objects (e.g. $Object_1$ in Figure 1) but activity systems also coalesce on shared objects (e.g. $Object_2$ and $Object_3$ in Figure 1). Whereas $Object_1$ represents a more isolated object with respect to a specific subject (e.g., graduating in a STEM major), $Object_2$ and $Object_3$ represent "a collectively meaningful object constructed by an activity system" and an object that is "potentially shared or jointly constructed" between interacting activity systems (Engeström, 2001, p. 136), respectively (e.g., creating an infrastructure for inclusion in higher education STEM programming that promotes success and retention for women in STEM).

Mediating artifacts, *rules*, *community* and *division of labor* all facilitate the relationship between *subjects* and *objects*. *Mediating artifacts* are culturally produced and culturally situated tools and signs or, more generally, affordances that are employed by the subject to achieve the object. In the case of the student with the object of graduating with a STEM degree, mediating artifacts might include textbooks, the classroom, online learning resources, a student's perception of their professor, and visiting office hours. *Rules* designate the specific forms of governance to which a subject and the other elements within the activity system adhere when trying to achieve the object. For the student with the object of graduating with a STEM degree, these *rules* might include late homework and other grading policies and practices, student codes of conduct, and cultural expectations of one's family and friends as they relate to higher education. The *community* refers to the participants relevant to the activity system whose actions may influence the relationship between the subject and object, for example, the student's faculty mentors, professors, family, and friends. Finally, the *division of labor* points to both the implicit and explicit roles of the community members. A division of labor relevant for the student may include professors that deliver content knowledge, faculty mentors who might help the student understand the real-world implications of their classroom learning through a research experience, and family members and friends who might provide moral support to help maintain the student's confidence, and who may perpetuate social expectations and norms that the student unconsciously adheres to.

According to Engeström (2001), five principles serve as the foundation of activity systems. The first principle is that an object-oriented activity system, one mediated by artifacts and seen in relation to other activity systems, is considered to be the primary unit of analysis. The second principle is that activity systems are *multi-voiced*, meaning each system is composed of multiple points of view, as each participant within an activity system carries its own set of interests, traditions, and diverse histories (e.g., the division of labor between students, friends, family, faculty, and the institution within an activity system presents multiple, complex points of view).

The third principal, *historicity*, relates to the way an activity system transforms over time, and emphasizes the fact that an activity system must be contextualized within its own history (e.g. the rules and tools that mediate our students' movement toward her objective of graduating in a STEM major have changed over time) and within the broader history of the tools and traditions that have shaped it (e.g. the student activity system may be influenced by institutional and societal barriers emanating from our nation's history of unequal access to higher education). The fourth principal is that contradictions, or structural tensions that accumulate over time within and between activity systems, play a central role in creating disturbances (e.g. an instructor may be giving out extra credit for students who come in on the weekends to study without realizing it is disadvantaging those who need to work on the weekends to support their families and their education). The fifth principal elaborates on the potential for transformations within activity systems and illuminates how these disturbances can lead to innovation and change in an activity. In some cases, contradictions become intensified and participants begin to interrogate and move away from existing norms, often embarking on collective efforts to create change (e.g. in our example, the STEM student and her peers might advocate for a policy change in the way grades are awarded so that those who work on the weekends are not at a disadvantage). This process can result in *expansive* transformation, which is accomplished when the object of an activity is redefined to represent an even broader range of possibilities. For the student in our example, this could represent a move from the original object of graduating in a STEM major to the new object of helping to advance a more equitable infrastructure (e.g. through the proposal of new grading policies) so that diverse students have a better chance of graduating in STEM majors.

In this article, we use CHAT as a framework to identify and diagnose contradictions within and between activity systems, that become apparent through our systematic literature review of barriers to accessing undergraduate research experiences. While we utilize the subjects of students, faculty, and the institution as bases for three separate activity systems as a methodological tool for the purpose of analysis, we recognize that these stakeholders can also be seen to represent three aspects of a much larger system that informs undergraduate research experiences in postsecondary education. It is our intent to help identify key contradictions for each relevant stakeholder group (i.e., student, faculty, institution) and, evaluate how these contradictions overlap and inform one another in ways that prevent students and faculty from successfully engaging in successful collaborative research experiences. We assert that by diagnosing potential contradictions, and thus pointing to areas for potential transformation at institutions of higher education, we can promote more equitable access to undergraduate research experiences and the benefits they afford for all students, and specifically those of color, in STEM.

Methodology

Preliminary Non-Structured Literature Review

Toward our larger goal of investigating barriers to accessing undergraduate research for STEM students of color, we first conducted a preliminary, non-structured literature review concerning the following research question: *What barriers exist for students of color trying to earn STEM undergraduate degrees?* A barrier was conceptualized as something that contributed negatively to an undergraduate student's success (maintaining good enough grades to remain in good standing) and persistence (remaining in postsecondary education in a STEM degree program).

We identified relevant articles through the education-related online databases, JSTOR and EBSCOhost, using search terms relating to "minority", "underrepresented", "STEM", "barrier", and "undergraduate", as well as articles known to be relevant to the field per the first author's experience as a coordinator of a STEM diversity initiative with a focus on undergraduate research. The lead author then surveyed a total of 38 relevant articles (Appendix A) to generate a list of potential barriers for students of color in relation to STEM at the postsecondary level. When an author(s) of an article discussed something that contributed positively to success for students of color in STEM, we did not assume its absence to be a barrier to success unless it was referred to as one by the author(s). For example, if an author(s) mentioned that having role models of a similar race or ethnicity led to GPA gains for students of color, we did not automatically assume that a lack of such role models served as a barrier for students of color unless that was explicitly mentioned in the literature (which it was). The lead author only catalogued barriers when it was explicit or implied that the author was referring to the barrier as it pertained to success or persistence for students of color during their postsecondary educational experiences. It is important to note that barriers identified during the primary non-structured review were not always backed up by empirical data in the article being reviewed; in some cases, they were only mentioned in the article, for instance as citations that the article's authors deemed relevant. Thus, the lead author worked from an assumption that barriers mentioned in articles had been confirmed by the authors and the reviewers for that article, who are, collectively, experts in their fields.

The 38 articles that were the basis of the primary non-structured review yielded ten emergent categories of barriers to success for students of color in relation to STEM at the postsecondary level. These categories then became the basis for the structured literature search (described below) on barriers to accessing undergraduate research experiences for STEM students of color.

Structured Literature Review: Identifying Articles Addressing Barriers to UR

During the next phase of the literature review, we combined key words and phrases from the ten categories of barriers identified via the non-structured review with the search terms “undergraduate research”, “barrier”, and “students of color” to identify articles that addressed barriers in access to undergraduate research experiences (Appendix B). The lead author conducted each search using Google Scholar, which allowed us to search more holistically across multiple databases instead of just one (Zientek, Werner, Campuzano, & Nimon, 2018), and restricted searches to peer-reviewed journal articles published from 2000-2017, to generate a contemporary assessment of research-identified barriers to accessing undergraduate research that exist in higher education for STEM students of color.

A total of 10,093 Google Scholar search results were generated. Two authors (SP and LM) co-screened 30 papers identified through one Google Scholar search together to determine inclusion and exclusion criteria through an iterative process that let us determine whether criteria were accurately capturing or not the articles of interest. Once inclusion/exclusion criteria were determined, the lead author screened all 10,093 articles within a ten-day period between 9/26/17 and 10/5/17, to eliminate the need for performing another search as Google Scholar evolves in its listings (Appendix B). Titles were first used to eliminate articles that did not appear relevant to this study. To pass the first phase of screening, titles had to mention or imply the study related to two or more of the following foci – a STEM field, undergraduate research, students of color, or undergraduates - without invalidating one of these foci. A title invalidated one of the foci when it explicitly stated or implied the study was *not* about STEM, undergraduate research, students of color, or undergraduates (e.g., “Multiple case study analysis of young women's experiences in high school engineering” invalidated the focus on undergraduates by indicating the study was about high school students). Titles invalidating one or more of these foci were excluded.

When a title met these inclusion criteria, the lead author also screened the abstract. If the abstract mentioned or implied the study related to a STEM field *and* undergraduate students of color *and* barriers to accessing undergraduate research, the paper was included in our analysis. We excluded papers with abstracts that did not explicitly mention or imply the study related to a STEM field *and* undergraduate students of color *and* barriers to accessing undergraduate research. When a title met inclusion criteria, but no abstract was provided or was not obvious, the lead author skimmed the body of the text to see if the study related to a STEM field *and* undergraduate students of color *and* barriers to accessing undergraduate research; papers then meeting these criteria were then also included.

During the review of abstracts, we noted a lack of research on barriers to accessing undergraduate research specifically for students of color in STEM. This finding motivated us to relax our inclusion criteria when reviewing articles and also consider those that implied the study related more generally to undergraduate students and barriers to accessing undergraduate research (Figure 2).

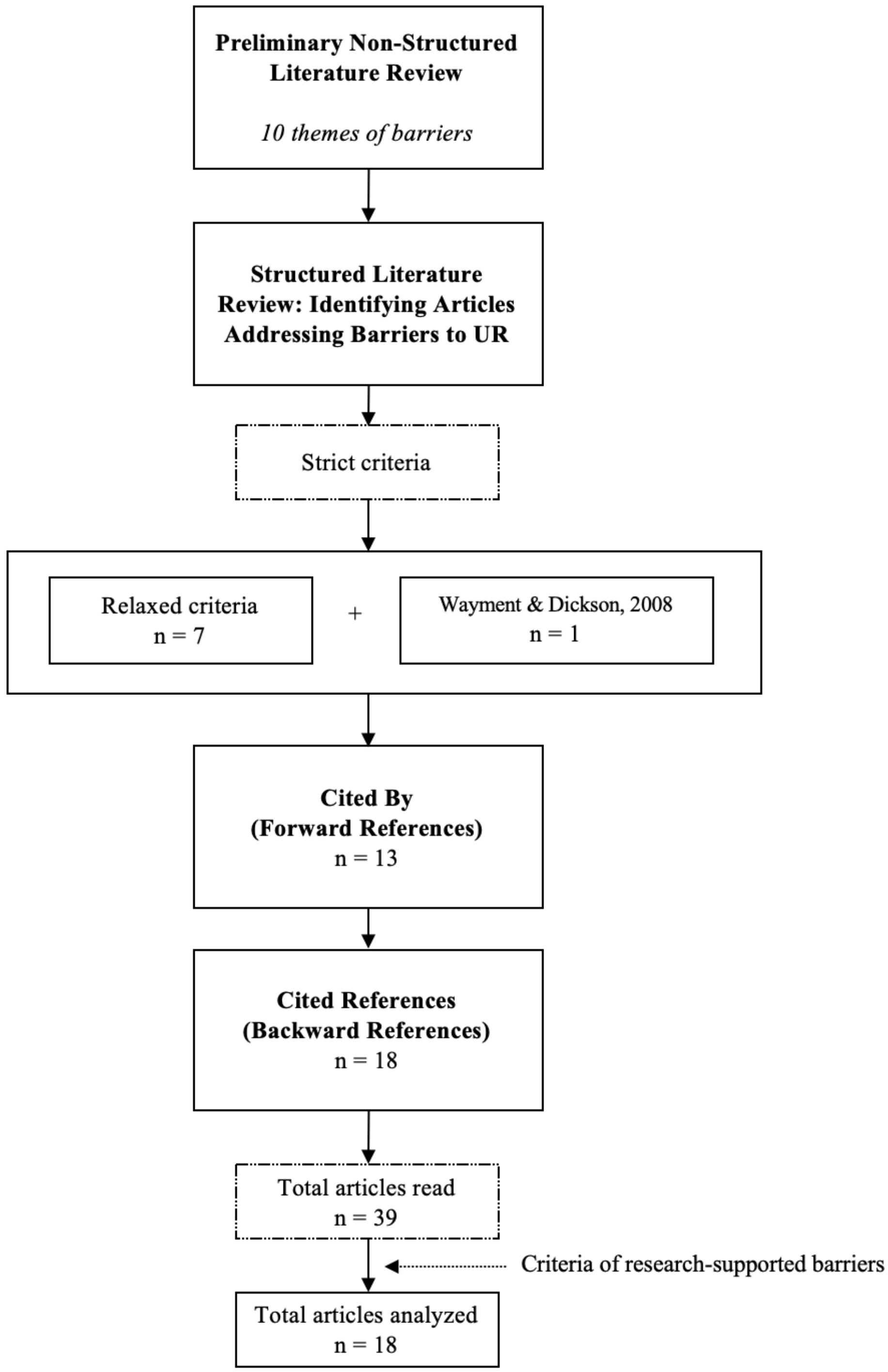

Figure 2. Flowchart outlining the methods and outcomes of our preliminary non-structured literature review and subsequent structured literature review which led to the final number of articles analyzed.

Thus, our focus widened to include barriers to accessing undergraduate research for all students. This means we were no longer solely focusing on research concerning the experiences of students of color or experiences exclusively within STEM. We also chose to include one paper that did not show up in the Google Scholar searches but that the authors knew to be relevant to this topic (Wayment & Dickson, 2008). These relaxed criteria yielded a total of eight papers for analysis from the 10,093 search results.

Using these eight papers, one author (LM) conducted forward and backward searches (papers cited by or citing those eight papers) using the same relaxed inclusion/exclusion criteria (Figure 2). All forward searches were conducted within a 24-hour period (April 6, 2018) and yielded a total of 221 articles whose titles and abstracts were screened against our inclusion/exclusion criteria detailed above. This resulted in another 13 articles for analysis. Backward searches yielded 383 articles whose titles and abstracts were screened against our inclusion/exclusion criteria, resulting in an additional 18 papers for analysis. After analyzing these 31 total articles resulting from forward/backwards searches, we noted that 13 did not attend to our topic of interest in the body of the paper regardless of meeting our criteria during title/abstract review. Thus, our final number of articles analyzed/discussed in the remainder of the paper is 18 (Figure 2).

Analysis Procedure for Structured Literature Review

Two authors (SP and JBG) employed a two-phase philosophical hermeneutic approach to interpreting the text within the 18 articles identified through the structured literature review (Trede & Loftus, 2010; Trede, Macklin, & Bridges, 2012). This is a qualitative approach that employs critical reflexive dialogue, by posing questions and drawing answers from the text. Our analysis proceeded in two phases. First, we independently read each article and recorded individual responses to the following three questions:

1. *Which barriers to accessing undergraduate research experiences are identified in the literature using original research?*
2. *What methods and central theories are used to explore barriers in access to undergraduate research experiences for students?*
3. *What implications were outlined for overcoming barriers to undergraduate research experiences for students?*

We then compared results, clarified inconsistencies, and settled on a shared interpretation of the text. On the rare occasion when a result offered did not make sense, we chose not to include it (e.g., "having research-led teaching associate deans in faculties so that they can integrate research and teaching strategy"; Brew & Mantai, 2017, p. 564). We did add one finding that was overlooked in our initial analysis of the articles as we re-reviewed articles during the final stages of writing. Our collective interpretations of the articles' responses to these questions is presented in the following section.

Results

Non-Structured Literature Review

The 38 articles included in the preliminary, non-structured literature review yielded ten emergent categories of barriers to success for students of color in relation to STEM at the postsecondary level (Appendix C). The first category of barriers was a lack of representation or a lack of role models. This category included the subcategories of 1) lack of representation at all levels within the college/university, 2) the absence of culturally relevant role models and peers, and 3) being considered to act as a representative of one's group. The second category was family and cultural barriers. This category included subcategories of 1) difficulty bridging cultural expectations and norms with expectations and norms in academia, 2) conflicting identities, and 3) absence of peer/family support or excessive peer/family pressure.

The third category was psychosocial barriers with subcategories of 1) exposure to stereotypes, 2) additive psychosocial effects, 3) physical side effects of psychosocial barriers, 4) pressure and doubt from self and others, 5) feeling conspicuous, 6) lack of belonging, 7) lack of identity, and 8) feeling inadequate. The fourth category was barriers associated with academic preparation with subcategories of 1) inadequate academic preparation and 2) lack of resources prior to college. The fifth category was financial barriers, which included subcategories of 1) high financial need and 2) a need to work. The sixth category was institutional barriers. This was broken into subcategories of 1) issues in the classroom/curriculum, 2) campus climate, and 3) faculty issues.

The seventh category was barriers associated with a lack of capital. Subcategories that emerged were 1) a lack of information and 2) inadequate human and cultural capital. The eighth category was historical barriers or barriers historically associated with STEM fields, including subcategories of 1) STEM cultural barriers, and 2) STEM claiming to be objective or neutral in nature. The ninth category was barriers associated with a loss of interest, which included subcategories of 1) growing disinterest in STEM and 2) greater interest in another field. Finally, the tenth emergent category was barriers associated with racism, including subcategories of 1) racism, 2) subtle racialized messaging, and 3) exclusion.

More detailed explanations of each sub-category, as well as examples, are provided in Appendix C. As mentioned above, these ten categories of barriers served as the basis for the subsequent structured literature search on barriers to accessing undergraduate research experiences for STEM students of color. They also encouraged us to put forth a set of hypotheses for how the ten categories of barriers for students of color in STEM postsecondary contexts could manifest as challenges to securing an undergraduate research position in an effort to highlight areas of study that deserve further attention.

What Methods and Central Theories are Used to Explore Barriers in Access to Undergraduate Research Experiences for Students?

There were some methodological and conceptual similarities shared among the 18 articles included in this review, summarized in Appendix D. Most of the researchers we reviewed collected data from faculty (Brew & Mantai, 2017; Jones &

Davis, 2014; Kierniesky, 2005; Morales, Grineski, & Collins, 2016; Shanahan, Walkington, Ackley, Hall, & Stewart, 2017; Spell, Guinan, Miller, & Beck, 2014), students (Mahatmya et al., 2017; Pérez Huber, 2010; Sens et al., 2017; Wolkow, Durrenberger, Maynard, Harrall, & Hines, 2014), or both (Hirst, Bolduc, Liotta, & Packard, 2014; Hurtado et al., 2011; Hvenegaard, Anne-Marie, Moore, & Wesselius, 2013; Schwartz, 2012; Wayment & Dickson, 2008). Researchers of one article collected data from students, faculty, and administrators (Hvenegaard et al., 2013). Tucker, Mulliner, and Wilson (2017) gathered data from both students and industry leaders who might serve as students' future employers. Perlman and McCann (2005) collected data from psychology "departments" but did not articulate whether these responses came from faculty or administrators. One set of authors did not gather data from human subjects (van Vliet, Klingle, & Hiseler, 2013). Instead, van Vliet et al. (2013) offered a non-structured literature review of challenges and benefits of mentoring undergraduates in counselling psychology, but did not provide a structured methodology.

Many of the articles we reviewed employed qualitative data collection and analysis strategies, either exclusively (Brew & Mantai, 2017; Hirst et al., 2014; Hvenegaard et al., 2013; Pérez Huber, 2010; Schwartz, 2012; Shanahan et al., 2017; Tucker et al., 2017; van Vliet et al., 2013) or in conjunction with quantitative methods (Hurtado et al., 2011; Jones & Davis, 2014; Perlman & McCann, 2005; Spell et al., 2014; Wolkow et al., 2014). Some just used quantitative strategies (Kierniesky, 2005; Mahatmya et al., 2017; Morales et al., 2016; Sens et al., 2017; Wayment & Dickson, 2008).

Common qualitative methods included individual interviews (Brew & Mantai, 2017; Hurtado et al., 2011; Pérez Huber, 2010; Schwartz, 2012; Shanahan et al., 2017; Tucker et al., 2017) and/or focus group interviews (Hurtado et al., 2011; Hvenegaard et al., 2013; Jones & Davis, 2014; Pérez Huber, 2010; Tucker et al., 2017), participant observation/ethnographic fieldwork (Schwartz, 2012; Wolkow et al., 2014), student achievement data (Hirst et al., 2014; Perlman & McCann, 2005), artifact analysis (Perlman & McCann, 2005), website visitation and undergraduate research participation data (Wayment & Dickson, 2008), or a literature review (van Vliet et al., 2013).

Questionnaires or surveys were used by many researchers (Hirst et al., 2014; Hurtado et al., 2011; Jones & Davis, 2014; Kierniesky, 2005; Mahatmya et al., 2017; Morales et al., 2016; Perlman & McCann, 2005; Schwartz, 2012; Sens et al., 2017; Spell et al., 2014; Wayment & Dickson, 2008; Wolkow et al., 2014). Some researchers used a pre-post research design (Hurtado et al., 2011; Sens et al., 2017; Wolkow et al., 2014) while another employed experimental groups for an intervention (Wolkow et al., 2014). A couple of sets of researchers explored change over time in response to an intervention, first gathering data to inform the development of an innovation, and then studying the impacts (Wayment & Dickson, 2008; Wolkow et al., 2014).

Some researchers explored phenomena across institutions or type of institutions (Hurtado et al., 2011; Jones & Davis, 2014; Kierniesky, 2005; Mahatmya et al., 2017; Morales et al., 2016; Perlman & McCann, 2005; Shanahan et al., 2017; Spell et al., 2014; Wayment & Dickson, 2008; Wolkow et al., 2014). While some articles focused specifically on STEM fields (Hirst et al., 2014; Hurtado et al., 2011; Morales et al., 2016; Schwartz, 2012; Sens et al., 2017; Spell et al., 2014; Wolkow et al., 2014), others focused more broadly across disciplines (Hvenegaard et al., 2013; Pérez Huber, 2010; Shanahan et al., 2017). Four articles specifically focused on psychology (Kierniesky, 2005; Perlman & McCann, 2005; van Vliet et al., 2013; Wayment & Dickson, 2008) and one focused on disciplines related to property and construction (Tucker et al., 2017). Three articles did not specify a disciplinary focus for their studies (Brew & Mantai, 2017; Jones & Davis, 2014; Mahatmya et al., 2017).

We noted a fairly limited use of theoretical/analytical frameworks in the articles we reviewed. Of the five articles that did put forth frameworks, only two situated their work within critical lenses. Pérez Huber (2010) employed critical race theory (specifically, Latina/o Critical Race Theory) as both a theoretical and analytical framework to explore racist nativism (e.g. defined as "the assigning of values to real or imagined differences in order to justify the superiority of the native, who is perceived to be white, over that of the non-native, who is perceived to be People and Immigrants of Color, and thereby defend the native's right to dominance," p. 81) and intersectionality (e.g. the interconnected nature of one's various identities, including those associated with gender, race, and class). Schwartz (2012) utilized cultural historical activity theory to illuminate power structures in learning environments, and issues of race and marginalization within activity systems involving diverse actors. However, the theory was used primarily as a conceptual and methodological framework to guide the study but was not used as an analytical framework to situate findings. findings. Morales et al. (2016) utilized organizational citizenship behavior and social exchange theory as theoretical frameworks to explore faculty willingness to mentor undergraduate researchers from outside institutions. These theories were used to guide the methodology of their study (i.e. by informing the variables used in their survey) and were revisited as analytical tools to situate their findings. Mahatmya et al. (2017) situated their work in a framework of workforce diversity that privileges organizational, individual, and historical contexts as factors informing "diversity of inclusion" (p. 3) to explore the reasons students choose to participate in undergraduate research across demographic groups and institution types. Tucker et al. (2017) drew on a theory of students' research preparedness, first established by Shaw, Holbrook, & Bourke (2013), in exploring how prepared students perceive themselves to be before engaging in research. In this study, the theory of research preparedness was used as an analytical tool as the authors connected high-level themes to findings that related to students' perceptions of their own research preparedness. Positivist or postpositivist assumptions were noted in the methodologies of eleven of the articles we reviewed (Hurtado et al., 2011; Jones & Davis, 2014; Kierniesky, 2005; Mahatmya et al., 2017; Morales et al., 2016; Perlman & McCann, 2005; Sens et al., 2017; Shanahan et al., 2017; Spell et al., 2014; Wayment & Dickson, 2008; Wolkow et al., 2014).

Which Barriers to Accessing Undergraduate Research Experiences are Identified in the Literature Using Original Research?

Numerous barriers in access to undergraduate research were identified across the 18 articles with original research. Each section below represents a different category of barrier that was identified.

Physical resource issues

Lack of support/resources for students on how to navigate undergraduate research (n=5)

Five articles mentioned a lack of institutional resources and support to help students navigate undergraduate research as a barrier to access. For example, Wayment and Dickson (2008) noted that the lack of an informal system for advertising opportunities for research in a mid-sized psychology department stood in the way of student access to research. Mahatmya et al. (2017) surveyed students at four different higher education institutions about their reasons for not participating in research and found that students pointed to a lack of information about opportunities. The authors claimed these barriers indicate a lack of institutional support for students who might have engaged in research if additional resources were available (e.g. offering information about available opportunities, providing support in finding a mentor, and helping students prepare to secure a position).

Sens et al. (2017) added that students from rural North Dakota lacked information about the importance of undergraduate research when pursuing careers in research or health care and were not made aware of opportunities while in college. However, no data was provided to support this claim. During focus groups with students in the United Kingdom, Tucker et al. (2017) found that participants felt they needed more institutional support for preparation before they entered a required research experience. Similarly, during focus group discussions with students at a small liberal arts institution, Hvenegaard et al. (2013) added that a lack of information about directed studies courses before enrolling was a main challenge to participation. However, it is important to note that research experiences were required for students in both of these last-mentioned studies, so access was guaranteed regardless of these challenges.

Lack of financial resources for research-related supplies (n=3)

Another barrier cited in the literature was a lack of financial resources to help pay for research-related supplies. Jones and Davis (2014) surveyed faculty at two different institutions and found that limited funds for research supplies were a common issue that detracted from faculty's experience as mentors. A lack of research equipment and supplies was also highlighted by research participants in Morales et al. (2016) as something that would prevent them from serving as mentors. Some research participants in Morales et al. (2016) also noted that without conference travel funds for students and faculty, they would be unwilling to serve as mentors. During interviews with faculty mentors and their mentees, Schwartz (2012) discovered that institutional resources to support undergraduate research were so scarce that faculty sometimes utilized their personal income to fund these experiences for students.

Lack of space (n=3)

A lack of physical space was highlighted as a barrier in three articles. For example, Brew and Mantai (2017) noted that external research facilities at a large research institution in Australia are closed during the month of January, a time between fall and spring semesters at many universities, which is presumably when students could spend additional time engaging in research experiences. A lack of space was also addressed as an issue for community college faculty who were engaged in undergraduate research partnerships with community college students and faculty at four-year institutions (Hirst et al., 2014). While it meant access to larger research facilities and equipment, community college faculty expressed frustration regarding the lack of space and research infrastructure at their home institutions. A shortage of space to support undergraduate research was also noted in a review by van Vliet et al. (2013) as a challenge to mentoring specifically within counselling psychology.

Too few research opportunities available (n=3)

Sens et al. (2017) noted that too few research experiences are available in the first place, although no data was provided to actually support this claim. van Vliet et al. (2013) echoed this concern in their review of barriers to mentoring in counseling psychology. Mahatmya et al. (2017) surveyed students at four different higher education institutions about their reasons for not participating in research and found that students pointed to an inability to find a mentor or the fact that they applied but were not accepted into a research position, indicating that research positions are highly competitive.

Distance from resources (n=2)

Shanahan et al. (2017) found that, in the eyes of potential faculty mentors, distance from an institution and, thus, its resources, could serve as a barrier to productive mentoring relationships for students who seek undergraduate research opportunities through online platforms. In this article, faculty felt that "the mentor's personal preferences, experience using communication technologies, and to some extent the norms of the particular discipline affected the perception of the potential for online mentoring" (Shanahan et al., 2017, p. 9).

Distance from research-related resources was also addressed as an issue for community college faculty who were engaged in undergraduate research partnerships with community college students and faculty at four-year institutions (Hirst et al., 2014). While it meant access to larger research facilities and equipment, community college faculty found it too time intensive to commute to the university to mentor students.

Lack of support personnel (n=2)

Special attention was given in the literature to frustrations with a lack of personnel to help scale undergraduate research efforts. For example, the academics interviewed by Brew and Mantai (2017) felt that the lack of a centralized undergraduate research unit on campus meant the various processes for involving students in undergraduate research across campus were uncoordinated, which led to duplication of efforts by administrators. One participant interviewed noted they could not pay tutors enough to sufficiently support students in course-based research experiences. In the context of community colleges, Hirst et al. (2014) also found that faculty were frustrated by the lack of infrastructure and institutional support to help order supplies.

Lack of resources for undocumented students (n=1)

One article addressed a barrier specific to accessing undergraduate research from the perspective of an undocumented student. In a study exploring the intersectionality of Chicana college students, Pérez Huber (2010) interviewed an undocumented Chicana student who was altogether unable to access state and federally-funded programs that supported participation in undergraduate research because of her status. The author highlighted many other barriers that undocumented students face (e.g. internalization of racist nativist beliefs, discomfort and perceived hostility toward their group in educational environments, a lack of access to college financial assistance programs, and a lack of access to educational resources, including college); however, these were not explicitly considered in relation to participation in undergraduate research. While this is an important finding that deserves further exploration, it is important to note that accessing undergraduate research was not the primary focus of this article.

Lack of time

Lack of faculty time (n=10)

Ten articles positioned faculty as gatekeepers to undergraduate research experiences and pointed to a lack of faculty time as a factor preventing faculty from serving as mentors or supporters of undergraduate research for students. For example, in one study, Jones and Davis (2014) surveyed faculty at two separate institutions (one regional liberal arts college and one Research I institution) and participants responded that faculty time was a major barrier in the way of providing opportunities for undergraduate research. More than 71% of active research mentors at the liberal arts college noted that time was one of their top three challenges, although this category included both faculty and student time. Faculty at the Research I institution noted that faculty time was a barrier across all disciplines, although it was most problematic in lab-based disciplines.

Hirst et al. (2014) and Morales et al. (2016) both found faculty saturation (i.e., a lack of time) to be a barrier for students seeking undergraduate research experiences at institutions other than their own. Wayment and Dickson (2008) also reported that faculty time (in this case, time spent managing heavy teaching loads) was a barrier to providing opportunities for undergraduate research, although it is not clear which methods were used to support this claim.

A lack of faculty time was also mentioned specifically in the context of course-based undergraduate research experiences. For example, Spell et al. (2014) found that, across institution types, a lack of faculty time to create new research experiences was the biggest barrier to implementing opportunities for research into biology laboratory classes. Both Brew and Mantai (2017) and Hvenegaard et al. (2013) supported this claim more broadly with their findings that time to effectively implement research experiences in courses was considered to be a barrier across a wide range of disciplines by both administrators and instructors. Brew and Mantai (2017) also noted that it can take a long time for new faculty to get set up to begin research, which can delay opportunities for students.

This barrier grows even more salient as the benefits of undergraduate research become more well-recognized. For example, Shanahan et al. (2017) highlighted the views of award-winning research mentors who can feel an increase in student demand for research experiences with them, a demand that they cannot meet. Through faculty interviews and a review of the literature, respectively, both Schwartz (2012) and van Vliet et al. (2013) found that faculty pressure to advance one's career and manage competing work foci contributed to a lack of faculty time to mentor students.

Lack of student time (n=6)

A lack of time was also documented as a barrier to accessing undergraduate research for students in six articles. Using data from four institutions (i.e. a public doctoral university with High Research Activity based on Carnegie classification, a private doctoral university with Moderate Research Activity, a public Master's College with high undergraduate enrollment, and a private baccalaureate college with small undergraduate enrollment), Mahatmya et al. (2017) found that time was a barrier to participation in undergraduate research for students across demographics and institutions. The authors also found that students identifying as "seniors" in academic standing selected barriers, including a lack of time, significantly more frequently than students at other standings. Hirst et al. (2014) reported that 11% (2 of

19) of community college students responding to a survey about an undergraduate research partnership program at a nearby four-year institution indicated time was a barrier to their participation. Unfortunately, the authors did not indicate whether students felt that time was a barrier to their success within the program, a barrier to their participation in undergraduate research, or both. Finally, in a study of barriers to participation in directed studies courses, which the authors defined as “1-2 semester long courses involving one-on-one instruction with a faculty mentor, and with a focus on student-led independent research” (p. 1), Hvenegaard et al. (2013) found that some students at a small liberal arts institution felt participation in these research-intensive courses was very time consuming and difficult to fit into the existing course load, especially since there were research-related tasks for students to complete before the term started.

While the articles mentioned above pointed to a lack of student time as a barrier from the student perspective, several papers reported student time as barrier from the faculty perspective, as in Jones and Davis's (2014) study in which some faculty members at a Research I institution noted that undergraduate research experiences required, at a minimum, 15 hours per week commitment from students, outside of other course/program requirements. Faculty also indicated that students who were unable to devote this amount of time (those students dubbed “drive-by researchers”) were not encouraged to engage in research, since time devoted to a research project appeared to serve as a reflection of a student's dedication to research more broadly. However, it was unclear whether faculty research participants themselves were not encouraging these students or whether they were referring to faculty at large as being responsible for not encouraging participation of “drive-by researchers.” Jones and Davis (2014) also found that timely completion of scientific-writing and research methods courses were central to successful placement into research positions, adding more time constraints on students. Time as a barrier for students also appeared in van Vliet et al.'s (2013) review of literature on mentoring in counseling psychology. Similar to Jones and Davis' (2014) assertion above, van Vliet et al. (2013) outlined one paper which recognized that academic obligations and obligations outside of school detract from the time one can commit to research activities. Finally, Brew and Mantai (2017) interviewed twenty academics with an interest in developing undergraduate research opportunities and found that some felt the shortness of semester breaks meant there was not enough time for students to engage in research projects.

Lack of faculty incentives

Lack of compensation for teaching (n=6)

In a study regarding course-based undergraduate research (CURE) experiences by Hvenegaard et al. (2013), instructors indicated the lack of remuneration to be a concern. In this same study, administrators also noted that developing a system for faculty compensation was a challenge. Kierniesky (2005) found that across institutions with differing levels of selectivity, few faculty respondents reported extra compensation for engaging students in undergraduate research and few indicated it was established as part of their regular teaching load (11.7% and 37.2%, respectively). Over half of respondents (53.7%) indicated that engaging students in undergraduate research was done as overload. In a review of the literature on mentoring within counseling psychology, van Vliet et al. (2013) reported that a lack of incentives in the form of teaching credits served as a barrier to offering opportunities for undergraduate research. This lack of compensation for heavy teaching loads was echoed as a concern by Wayment and Dickson (2008) when considering barriers in access to undergraduate research within a mid-sized psychology department, although their methods for establishing this claim were not clear. In a study exploring the extent of research-based psychology coursework across the nation, Perlman and McCann (2005) noted that faculty did not often receive teaching credit for overseeing research-based courses. Interestingly, faculty were least likely to receive teaching credit for special topics and advanced research courses, those that were most likely to emphasize research as their primary objective. Most of these were taught as overload. Research participants in Morales et al. (2016) also noted a lack of reassigned faculty time and teaching credit would prevent them from serving as mentors.

Lack of faculty recognition/promotion and tenure guidelines rewarding mentoring (n=4)

Jones and Davis (2014) found that faculty uncertainty around how mentoring was assessed within the promotion and tenure system was prevalent at both teaching-focused and research-focused institutions. Schwartz (2012) expanded on this in reporting that faculty felt compelled to wait to mentor undergraduates until after tenure was granted because mentoring would not contribute to their professional advancement. In a review of the literature on mentoring within counseling psychology, van Vliet et al. (2013) report that no recognition within promotion and tenure guidelines, a lack of incentives in the form of few resulting publications, and no awards all served as barriers to offering opportunities for undergraduate research. Research participants in Morales et al. (2016) also noted a lack of recognition in the form of reduced service obligations would prevent them from serving as mentors.

Lack of financial incentives in summer (n=2)

In one study, community college faculty reported that insufficient financial incentives were a barrier to mentoring their own students in a partnership program with researchers at four-year institutions during summer (Hirst et al., 2014). Here, faculty participants indicated they could make twice as much money teaching two courses during summer, which would span the same time period as the partnership program. In another study, Morales et al. (2016) found that a lack of summer faculty stipends would prevent some faculty respondents from serving as mentors.

Lack of faculty competency and need for professional development related to undergraduate research (n=2)

Brew and Mantai (2017) reported that some academics felt "academic attitudes/mindsets and lack of knowledge or skills of how to implement research-based learning" (p. 557) was a key constraint in implementing research experiences for undergraduates. This was combined with participants' concern that faculty should be attending professional development sessions to improve their understanding of how to effectively offer undergraduate research experiences but were unwilling to participate, possibly due to what the authors refer to as ‘academic arrogance’. In addition, research participants in Morales et al. (2016) noted that without the development of faculty learning communities and faculty (and student) professional development workshops, they would be unwilling to serve as mentors.

Personal/emotional costs to faculty (n=1)

Schwartz (2012) alluded to personal and emotional costs to faculty offering opportunities for undergraduate research. In this article, faculty interviewees noted that caring deeply about and supporting young students of color, especially towards helping students build identity and confidence (i.e. by talking with them about professional but also personal issues) was hard work. Despite this hard work, faculty felt there was no institutional commitment to offer additional support, including financial support, to students and faculty engaging in undergraduate research partnerships. When combined with other professional and financial costs, faculty felt that these costs outweighed the benefits of mentoring students of color, causing mentors to take fewer, or no additional students.

Student and faculty perceptions of lack of student readiness to participate in undergraduate research (n=9)

One frequently addressed barrier to accessing undergraduate research across the articles was a lack of student research readiness. Mahatmya et al. (2017) for example, used a multi-institutional survey of students and documented a felt lack of research readiness on the part of students prevented them from engaging in undergraduate research. Specifically, across institutions and demographic groups, first year students were more likely to indicate lack of readiness as a barrier, even though first- and second-year students were more interested in participating in undergraduate research than juniors and seniors. Via focus groups with students, Tucker et al. (2017) reported that students felt that they had low confidence and a lack of ability to do research; however, it was not clear in this study whether this low confidence and lack of preparedness prevented students from participating in undergraduate research or whether students were already participating, in which case this is more of a barrier to success within an undergraduate research experience than one to accessing the experience itself.

Several articles addressed a lack of student preparation from the faculty perspective. For example, in the context of course-based undergraduate research, Hvenegaard et al. (2013), reported that instructors felt students were unprepared and administrators noted a lack of student academic ability or ability to work independently was a barrier to effective implementation of directed studies courses. Brew and Mantai (2017) also found that academics felt some students were not ready to engage in research, especially those who were struggling academically. The authors made the point that a lack of research readiness came with safety and health concerns. Jones and Davis (2014) found that faculty at two separate higher education institutions, a regional liberal arts college and a Research I institution, were selective about the students they brought into their research teams and that student quality and preparation/performance in class was critical. In this study, faculty from both institutions expressed issues with student preparation toward facilitating successful research experiences. Research participants in Morales et al. (2016) noted a lack of pre-training of undergraduates would prevent them from serving as mentors. A lack of student preparation for research experiences in introductory biology laboratories was also cited by Spell et al. (2014) as a key barrier cited by faculty across institution types, but most prominently in two-year colleges, minority-serving institutions, and public institutions.

In a program evaluation article outlining a health sciences-related undergraduate research program, Sens et al. (2017) highlighted the fact that rural high school education does not prepare students for undergraduate research experiences. However, no data were provided to support this finding. Finally, van Vliet et al. (2013) highlighted several articles in counseling psychology that pointed out that undergraduates do not have the same level of research skills as graduate students, which meant faculty are required to invest more time when working with them.

Student lack of interest in, and motivation for, participation in undergraduate research (n=8)

A lack of student interest in research was addressed in several articles. For example, during focus groups, Tucker et al. (2017) found that students studying property and construction in the United Kingdom expressed a need to be interested in the work to successfully engage in undergraduate research. Mahatmya et al. (2017) found that a lack of student interest served as a barrier in access to undergraduate research for students, especially for those not already planning to participate. In a review of literature on mentoring undergraduate researchers in counseling psychology, van Vliet et al. (2013) summarized one article that identified a lack of interest in a specific topic as a barrier preventing students from mentorship opportunities (Lei & Chuang, 2009). van Vliet et al. (2013) made the point in their article that scholars should work on making the field of counseling psychology more relevant to undergraduates in order to foster interest in research in this field.

Several articles pointed to the fact that research is overly intimidating and stressful for students. van Vliet et al. (2013) reviewed an article that found 14 doctoral students in counseling psychology felt that research was difficult, lonely, anxiety-provoking and not relevant enough to clinical practice (Moran, 2011). While this research did not provide evidence about realities for undergraduate students, van Vliet et al. (2013) alluded to the fact that these feelings likely persist during the those years as well. Hvenegaard et al. (2013) added to this sentiment more generally with their finding that students participating in directed studies courses at a small liberal arts institution viewed the research presentation requirement (just one component of the research experience) as very stressful and intimidating. Intimidation by research appears to extend to interactions with research faculty. Using senior exit surveys, Wayment and Dickson (2008) found that psychology students felt too intimidated to approach faculty about undergraduate research at all, or approached faculty after an opportunity had passed.

Hurtado et al. (2011) visited five college campuses (two primarily white institutions, two Hispanic-serving institutions, and one historically black college/university) and interviewed students, faculty, and administrators from undergraduate science research programs. The authors also found that students felt intimidated by the idea of approaching faculty, although this finding was not directly tied to the context of approaching faculty with the intention of participating in undergraduate research. The authors did mention, however, that students paid attention to cues from faculty about approachability and used those cues to make decisions about reaching out to faculty outside of class, which could translate into a barrier to accessing undergraduate research.

Not having a curricular requirement for all students to participate in undergraduate research was also noted as an institutional barrier to accessing these opportunities. For example, academics interviewed by Brew and Mantai (2017) viewed the lack of formal requirement for students to engage in research as one example of an institutional structure that constrains development of undergraduate research programming. In a second study that explored the prevalence of research-based experiences in psychology courses across the nation, questionnaires revealed that 21% of the 203 psychology departments that responded did not require that undergraduates participate in a research-based course (Perlman & McCann, 2005). Of course, this percentage varied according to institution type, with a greater percentage of departments at four-year institutions requiring a research-based course than the two-year institutions.

Finally, in a review of articles addressing the benefits and challenges of mentoring undergraduates in counselling psychology, van Vliet et al. (2013) highlighted one paper (Moran, 2011) that found students had ambivalent or negative feelings toward research in this field, likely because it is more practice-based than research-based, and point to several other papers that suggest undergraduates are not as research-ready as graduate students.

Student financial constraints (n=7)

Financial constraints were highlighted as a key barrier to participation for students in undergraduate research across several of the articles. When surveying undergraduates at four higher education institutions about barriers that prevent them from participating in undergraduate research, Mahatmya et al. (2017) found that 61% of students pointed to what the authors label as *instrumental* barriers, which included a “need to earn sufficient income during the academic year” (p. 6). The authors also found that seniors selected instrumental barriers significantly more frequently than students at other levels within their degree programs.

In another study, community college students who had participated in an undergraduate research partnership program with a nearby four-year college indicated the lack of pay impeded their participation. A faculty member surveyed in this study added that, “Other students have chosen not to participate in summer research more generally because the summer research stipend does not equal what they could earn at other jobs—income that is necessary to support more diverse family structures and greater financial needs than the traditional students [at the 4-year institution]” (Hirst et al., 2014, p. 15). van Vliet et al. (2013) mentioned one article in their literature review on mentoring in counseling psychology that pointed to financial constraints, including the fact that research coursework can mean additional fees, serving as a barrier to engaging in undergraduate research (Lei & Chuang, 2009). Finally, in trying to encourage participation in an undergraduate research program for students in rural North Dakota, Sens et al. (2017) noted that low student compensation served as an obstacle. However, there was no data provided to support this claim.

Several articles highlighted that financial resources to help pay for student stipends were missing at their institutions. Jones and Davis (2014) surveyed faculty at two different institutions and found that limited funds for student stipends were a common issue that detracted from faculty's experience as mentors. van Vliet et al. (2013) pointed to a lack of funds to support undergraduate researchers as one barrier in their effort to better understand challenges to mentoring specifically within counselling psychology. Morales et al. (2016) detailed that 42.4% of their faculty respondents claimed that without stipends for students visiting from other institutions, they would not agree to serve as mentors. Brew and Mantai (2017) interviewed academics and also found that money was a key constraint in implementing undergraduate research, although it is not clear whether academics were referring to financial incentives for faculty or financial support for student research.

Lack of undergraduate research in courses or issues with implementing undergraduate research in courses (n=5)

A number of articles pointed to poorly executed course-based research experiences, or issues with implementing undergraduate research in courses, as barriers to student access to research. For example, instructors teaching directed studies courses at a small liberal arts institution felt that the lack of specific guidelines and standards for teaching them were a primary challenge (Hvenegaard et al., 2013).

Administrators that were interviewed in this same study felt that one of the greatest challenges for instructors was defining the scope of a project and properly assessing student performance. Administrators admitted to their own set of challenges, including the ability to address instructor workload or compensation and consistently assessing directed studies courses. None of these barriers were actually detailed by authors in ways that indicated they were barriers to access; however, we assume that these perceptions stand in the way of scaling these offerings so that additional students can access them. Wolkow et al. (2014) extended these findings into the context of two-year institutions. In this study, student and instructor evaluations of an introductory biology course revealed that students, instructors, and support staff required instructional resources that were more customized for their needs and that students, instructors, and support staff could have used additional training while the course was being implemented. The authors found several other barriers associated with offering successful course-based undergraduate research experiences at the community college level, including a disconnect between lecture and lab content, lack of student comfort with lab equipment, and the fact that the course felt too rushed. While these may be seen as barriers to success in course-based undergraduate research experiences, and not access, they point to reasons why it is difficult to offer these experiences at community colleges altogether.

In another study, Brew and Mantai (2017) found that academics perceived large class sizes, complex ethics processes, and a lack of time in the curriculum to implement inquiry-based learning to all serve as barriers to offering course-based research experiences. These academics also indicated that instructors lacked the interest, knowledge, and compensation to effectively support inquiry-based learning in the classroom. While surveying psychology departments across the nation to better understand the extent of course-based research opportunities available to undergraduates, Perlman and McCann (2005) found that departments at several institution types had limited number of faculty members, indicating that few faculty members were available to teach research skills. The authors also noted that psychology research courses were mostly reserved for older students, which limits access for earlier-career students, and found that "40% of all courses had a research project of less than two weeks' duration, suggesting that students experience a lot of very brief research" (p. 11).

Spell et al. (2014) explored barriers to implementing research experiences into introductory biology laboratory courses. The authors surveyed biology faculty members at different institution types across the nation and found that the most important barrier across institution types was a lack of time for faculty to design new research experiences. Cost, class size, and a lack of student preparation were the most important barriers reported at two-year institutions. For research universities, the most important barriers were class size and the number of class sections. At minority-serving institutions, the most important barriers were cost, lack of student preparation, instructor resistance, and a lack of administrator support. Finally, the most important barriers at public institutions were class size, the number of class sections, and a lack of student preparation. Additional barriers listed in free responses fell into multiple, small categories (n = 22), including time for implementation, logistics, student attitudes, connection with lecture, creativity, and curricular resources, which suggested a strong contextual influence on implementation of authentic research experiences.

Social deterrents for students and faculty (n=4)

Four articles alluded to social influences on students and faculty serving as barriers to participation in undergraduate research. Mahatmya et al. (2017) found that students surveyed across four higher education institutions indicated that social barriers ("e.g., I don't know anyone who has done research", p. 6) prevented them from participating in research. In their review of articles addressing the benefits and challenges of mentoring undergraduates in counselling psychology, van Vliet et al. (2013) highlight Lei and Chuang's (2009) finding that job, family, and social commitments also stood in the way of being mentored in research. As van Vliet et al.'s (2013) article is a literature review, we assessed Lei and Chuang's (2009) finding more closely and found that the authors were alluding to the fact that students' perceived obligations related to jobs, family and social life, and academics all impose constraints on a student's time which could delay a student's progress in research, and potentially delay graduation if completion of a research project is required to finish one's degree.

Brew and Mantai (2017) found that, in certain departments, a lack of interfaculty communication about engaging students in undergraduate research prevented the exchange of views about possibilities for expanding and improving the quality of research experiences, leading to fewer opportunities. Finally, in the context of course-based undergraduate research, Hvenegaard et al. (2013) revealed that instructors felt that interpersonal/communication issues with students were a challenge to implementation of successful research experiences in the classroom.

Negative faculty perceptions regarding student capacity/competency (n=3)

Several researchers argued that faculty perceptions of student capacity and competency served as a barrier to students' access to undergraduate research. Whereas the previous category relates more to social constraints, including social pressures and a lack of social interaction/communication, this category focuses more on the negative ways in which faculty perceive students. For example, in Brew and Mantai (2017), faculty noted that undergraduate research was not appropriate for those who were not performing well academically, did not have a good attitude towards research, or did not understand the relevance of research. Jones and Davis (2014) echoed these findings in reporting on their interviews with faculty at two different institution types, a regional liberal arts college and a Research I institution. In this study, faculty from both institutions expressed issues with student quality and commitment toward facilitating successful research experiences. The faculty interviewed by Shanahan et al. (2017) took this one point further in positing that some students from historically underrepresented groups have lower academic records, which could impede their access to undergraduate research. In this context, the faculty who were interviewed hoped that faculty would move past this requirement and accept students with average grades.

Lack of institutional commitment to undergraduate research (n=3)

It is important to identify the distinction between barriers that place the agency on faculty and those that place agency of the institution. Ultimately, there were several researchers who emphasized agency of the institution, in essence processes/structures that happen at the institutional level, as creating barriers to accessing undergraduate research. Both Brew and Mantai (2017) and Jones and Davis (2014) made the point that rewarding faculty research over mentoring and teaching sends the message to faculty that little value is afforded to the latter two experiences by the institution. Taking a broader perspective on the lack of institutional commitment to undergraduate research, Schwartz (2012) found that many faculty members felt their institution lacked a vision to support a larger culture of research, either through partnering with larger research universities with more robust resources or by acknowledging and supporting the work that faculty were currently doing to support students in research by providing funding.

Student lack of awareness of undergraduate research benefits and opportunities (n=3)

In a previous section, we outline that lack of support and/or resources to help students navigate undergraduate research served as a barrier to accessing these experiences. Other articles pointed to the fact that students were simply unaware of the benefits of undergraduate research, or the existence of opportunities themselves, which served as another barrier to participation. For example, during student focus groups, Tucker et al. (2017) noted that the benefits resulting from research were discussed relatively few times, indicating students were largely unable to identify reasons for participating. Wayment and Dickson (2008) identified several key barriers that related to this lack of student awareness within the psychology department at Northern Arizona University: 1) students were not aware of the benefits of undergraduate research opportunities until too late in their undergraduate programs, 2) there was a lack of student awareness of undergraduate research opportunities, or unequal awareness, caused by a lack of formal system for advertising opportunities, and 3) student successes or products resulting from undergraduate research experiences were not being properly publicized to promote involvement. In a review of relevant literature, van Vliet et al. (2013) detailed more broadly a lack of student awareness of the field of counseling psychology that prevents students from participating, or even realizing they can participate, in undergraduate research related to this discipline.

Lack of faculty diversity (n=2)

Interestingly, only one article addressed a lack of diversity as an institutional barrier to accessing undergraduate research. Specifically, van Vliet et al. (2013) highlighted several articles in their review that point to the lack of diversity among counseling psychology faculty. The authors positioned this lack of faculty diversity as a barrier to student access to undergraduate research by pointing to the literature that supports the idea that students often prefer mentors from similar gender and racial/ethnic backgrounds and may be deterred from these experiences by a lack of diversity among potential mentors. One faculty program director interviewed by

Hurtado et al. (2011) felt that faculty inaccessibility was exacerbated by the scarcity of science faculty from historically underrepresented groups. The director highlighted that “there are very few professors who share [students’] background, so there might be something. . . off-putting or intimidating about a department where they never see anyone who looks like them who made it” (p. 571). However, it was not clear in the text whether this barrier relates to accessing faculty in general, or accessing mentors for undergraduate research experiences.

Discipline-specific barriers (n=1)

In their review of barriers to mentoring in counseling psychology, van Vliet et al. (2013) highlighted that a struggle for recognition of their discipline as research-rigorous prevented students from engaging in research. A lack of visible student-faculty partnerships with other departments was also highlighted as a barrier related to a lack of research infrastructure in counseling psychology.

What implications were outlined for overcoming barriers to undergraduate research experiences for students?

Here, we found that implications put forth by authors were largely positioned as recommended strategies for overcoming barriers to accessing opportunities for undergraduate research, which emanated from their research findings.

Curricular implications

CUREs

The authors of six articles highlighted the importance of CUREs for broadening participation in undergraduate research since these offerings allow for additional opportunities for student inquiry. For example, Spell et al. (2014) pointed out that faculty struggle to balance teaching and research identities and one way of overcoming this is by integrating the faculty's research agenda into the curriculum. Shanahan et al. (2017) also mentioned that offering undergraduate research experiences within courses should be prioritized. Brew and Mantai (2017) took this a step further by pointing out that growing a culture of evidence-based teaching practices would mean additional opportunities for students to participate in the types of inquiry that are characteristic of undergraduate research experiences. The authors indicated that students would be motivated to engage in undergraduate research if academic credit was offered as an incentive and that examples of offering undergraduate research for credit should be provided.

Other implications highlighted by Brew and Mantai (2017) that would serve to promote course-based undergraduate research experiences include the creation of three-hour periods for lecture, introducing ‘flipped’ classrooms which provide time for inquiry-based learning, and developing a facilitated program to support the creation of courses that integrate research. The authors also point out that curricular implications such as those noted above would be most effective when paired with associated policies like simplifying ethics requirements and requiring faculty to submit proposals for new course-based undergraduate research experiences. Exposure to this type of inquiry in the classroom could inspire students to seek out additional inquiry-based undergraduate research opportunities outside of the classroom.

Wolkow et al. (2014) suggested institutions help faculty and support staff become more comfortable implementing CUREs at two-year institutions, which include a large proportion of STEM students of color and those from a low socioeconomic status. The importance of this implication was echoed by Hirst et al. (2014) who also called out a need for additional support to promote CUREs at two-year institutions in order to increase access and inclusion.

Perlman and McCann (2005) outlined several implications for expanding access to undergraduate research opportunities, especially through course-based offerings. Specifically, the authors called for the promotion of psychology programs that required undergraduate research, offering and requiring more courses wherein undergraduate research in central, and offering more robust undergraduate research experiences, where students work alongside faculty from start to publication of research.

Better/earlier student preparation

The authors of nine articles called out the importance of better preparing undergraduates to engage in research and preparing them earlier in their academic programs. For example, Perlman and McCann (2005) argued for the importance of promoting undergraduate research experiences earlier in the undergraduate career (i.e., prior to junior year). Interviewees in Shanahan et al. (2017) also felt that earlier and more consistent undergraduate research experiences should be prioritized. van Vliet et al. (2013) felt this was true specially in counseling psychology wherein it would be critical to emphasize early on the importance of research in professional practice and to foster more positive feelings about research.

Morales et al. (2016) put forth the importance of pre-training of students with regards to research content and skills. Hvenegaard et al. (2013) argued that enhancing communication and organization of directed studies courses would serve to enhance awareness and increase student preparedness. The authors also noted that faculty should boast the benefits of undergraduate research to potential student participants to encourage awareness. However, the authors also noted that they did not survey faculty members who chose *not* to supervise undergraduate researchers. Thus, the perceived challenges to offering undergraduate research experiences and implications outlined in this article may be lacking. Sens et al. (2017) also found it helpful for students to understand the value of undergraduate research experiences, including how these experiences can support their future career, which can be seen as a form of preparation for research experiences. To support preparation for, and rigor of, research experiences, Brew and Mantai (2017) suggested coordinating efforts to offer progressively more holistic and challenging undergraduate research experiences throughout a students' postsecondary programs.

Tucker et al. (2017) highlighted the importance of early exposure to undergraduate research readiness to prepare students for research experiences throughout their degree programs and, ultimately, for competitiveness when entering the workforce. The authors highlighted two new modules that were introduced into the first- and second-year curriculum to support research readiness. Making research more exciting and interesting to early career students was one strategy that was suggested. It is also important to help students articulate what research is and how they can benefit from engaging in research. The authors made the important point that "if students are not involved in research experiences early on in their studies it may hamper their desire and ability to conduct research effectively, their understanding and awareness of the benefits and relevance of research skills, and motivation to continue with research" (p. 207).

Mahatmya et al. (2017) highlighted the importance of developing students' perceptions of preparedness as a key player in promoting participation in undergraduate research. This study outlined the need for college readiness programs to include research readiness in order to increase access for early-career students who, according to this study, were less likely to participate in undergraduate research but were more interested in undergraduate research than upper-division students.

Implications related to marketing and highlighting importance of undergraduate research for students and faculty

The authors of eight articles pointed to implications related to marketing and elevating awareness of the importance of undergraduate research. Jones and Davis (2014) highlighted the necessity of institutional support, such as the establishment of centralized offices for undergraduate research, as a sign of commitment to promoting and financially supporting a research culture for undergraduates. Wayment and Dickson (2008) also highlighted the importance of institutional affordances, like hosting a university-wide research conference for students to participate in, to promote a culture of undergraduate research that may encourage further participation.

Interviewees in Shanahan et al. (2017) also mentioned the importance of shared perspectives of faculty and administrators regarding the importance of undergraduate research and that undergraduate researchers need more institutionally-supported mentorship. Similarly, Schwartz (2012) pointed to the importance of promoting institutional and departmental culture of research.

Brew and Mantai (2017) highlighted institutional structures, policies, and procedures as the first place for enhancing the tradition of undergraduate research at a research institution and noted that having a department head supportive of undergraduate research is key when promoting a culture where undergraduate research is seen as normal. That is, a top-down approach to implementing undergraduate research programming and requirements was recommended, while recognizing that communication among colleagues is also critical. The authors recommended professional development opportunities for all levels of faculty, including instructors, where faculty can share ideas and learn about opportunities for fostering undergraduate research. They make the point that faculty should be somewhat assertive when highlighting the value of undergraduate research to colleagues. The authors also highlighted an undergraduate research newsletter, undergraduate research conferences, and an undergraduate research working group as helpful toward sharing ideas, although they do not indicate who these tactics are most useful for. Finally, the authors suggested supporting structures like disciplinary and undergraduate research student societies that provide a space for students to share ideas and learn about opportunities for undergraduate research.

Wayment and Dickson (2008) outlined more targeted tactics to more effectively distribute knowledge of undergraduate research opportunities and to offer more obvious and less intimidating means to apply for these opportunities (e.g., via a website, department newsletter, bulletin board, a standard online application, and faculty announcements in class). In this paper, implementing changes to overcome identified barriers led to increases in the number of students and faculty participating in undergraduate research and nearly all students who participated in undergraduate research went on to graduate school. van Vliet et al. (2013) pointed out that emphasizing early on the importance of research in professional practice can happen through educating undergraduates about the benefits of undergraduate research and making these experiences more widely visible and available. Two ways to increase visibility in counseling psychology offered by the authors were to advertise more widely online and to build research connections across disciplines.

Hirst et al. (2014) highlighted the importance of advertising the potential benefits of undergraduate research partnership programs between four-year institutions and community colleges in order to encourage expanded use of this model. Based on their findings which pointed to the power of social and experiential motivators for encouraging student participation in undergraduate research (especially for early-career students), Mahatmya et al. (2017) highlighted the importance of advertising undergraduate research as an experience that is available to all students. Finally, Jones and Davis (2014) took a more national perspective in highlighting the importance of distributing success stories of undergraduate research via the Council for Undergraduate Research and other organizations to encourage institutions and faculty to offer more opportunities.

Implications related to clarifying expectations around undergraduate research

The authors of four articles pointed to implications related to clarifying expectations around undergraduate research. For example, one implication highlighted in Sens et al. (2017) was the importance of clarifying expectations for faculty members mentoring undergraduate researchers and the role that clearer expectations could play in reducing faculty burnout. In the new undergraduate research model outlined by Sens et al., mentors were intentionally selected who were willing to commit to the program and had set aside time to do so. This new model outlined clear expectations of how much time faculty would spend and who could assist them. This contrasted to the old model wherein expectations were less clear, and faculty demonstrated various levels of involvement, which led to inconsistencies in mentoring commitments.

Another article pointed to the importance of clarifying expectations within CUREs. That is, one of the main implications related to access outlined in Hvenegaard et al. (2013) revolved around enhancing communication and organization for directed studies courses, including the importance of universities outlining clearer guidelines, standards, and goals for undergraduate research experiences by establishing assessment standards and disseminating information about these experiences with other students and faculty to encourage involvement.

Brew and Mantai (2017) noted that differing definitions of undergraduate research put forth by interviewees could make it difficult to clarify expectations related to these experiences. The authors pointed to the importance of helping faculty more broadly and accurately conceptualize what undergraduate research was and what it could be. They also put forth the implication that encouraging people at multiple levels (postdoctoral students, graduate students) to play a role in mentoring undergraduates would help faculty offer undergraduate research experiences. We assume this implication is directed toward faculty who may not realize mentoring an undergraduate researcher can be a team effort. Although it was not called out as a barrier to access in the article, differing definitions and conceptualizations of undergraduate research may be a barrier to offering undergraduate research experiences, for instance, if some faculty perceive them to be multi-year commitments similar to graduate student experiences. Would more faculty engage undergraduates in research if they knew undergraduate research experiences could be more flexible and could include shorter commitments? Confusion can be remedied by more clearly outlining expectations of undergraduate research through offering a more consistent definition.

Finally, Spell et al. (2014) pointed out that "conceptions of authentic research and barriers to its implementation likely vary from individual to individual and institution to institution" (p. 108). Thus, the authors highlighted the importance of evaluating how undergraduate research and barriers to accessing undergraduate research are perceived in a specific context before creating expectations for reform.

Implications relating to financial strategies and motivators for faculty

Making undergraduate research more cost-effective

The authors of six articles highlighted implications related to making undergraduate research offerings more cost-effective. While the authors did point out the importance of increasing funding for undergraduate research (including student stipends), van Vliet et al. (2013) suggested creating a system for students to receive course credit for research when funding was unavailable. Sens et al. (2017) highlighted the cost-effectiveness of an undergraduate research program that is cohort-based where students can share supplies. Morales et al. (2016) suggested encouraging faculty to use external funding opportunities, including those available from the National Science Foundation and National Institute of Health, to encourage mentoring of undergraduates from other institutions. Brew and Mantai (2017) highlighted the value of a coordinated system to support faculty who are applying for grants to support undergraduate research in order to increase the chances of securing funding for additional opportunities.

When referring to a research partnership program between four-year institutions and community colleges, Hirst et al. (2014) highlighted the need for additional faculty and student support, including expanded use of research space and resources at the four-year institutions in order to make these opportunities more widely available for community college students and faculty. Schwartz (2012) pointed to the importance of partnerships with research universities and their faculty in order to increase opportunities for undergraduate research. In this article, the costs associated with mentoring students of color meant that faculty took on fewer students.

The authors pointed out that faculty might be more willing to mentor additional undergraduates if the benefits outweighed the costs. Partnering with research labs that have more resources was offered by one interviewee as a more cost-effective solution to ease the strain on faculty.

The importance of faculty incentives

The authors of eleven articles pointed to implications related to the importance of providing faculty with incentives for mentoring undergraduate researchers. Most generally, Perlman and McCann (2005) argued for the importance of more support and rewards for faculty who offer opportunities for undergraduate research. Hurtado et al. (2011) also pointed to the importance of rewarding faculty for mentoring students outside the classroom and allowing faculty to worry less about publishing and more about teaching and mentoring. Brew and Mantai (2017) highlighted the importance of better preparing and rewarding faculty to offer undergraduate research via departmental and institutional structures and processes, including additional funding to support undergraduate research. The authors mentioned that faculty would be more likely to offer opportunities for undergraduate research if the university provided financial or workload rewards, including rewards for faculty who publish with students, build opportunities for inquiry into their courses, or secure grants that support student engagement in undergraduate research. Schwartz (2012) simply suggested supporting faculty by providing them with stipends.

Jones and Davis (2014) spoke to the importance of understanding faculty perceptions with relation to mentoring in ensuring the success of undergraduate research programs. Specifically, the authors suggested gathering formative data on faculty perceptions of undergraduate research in order to ensure faculty needs are met. This is especially important because if faculty do not feel supported, undergraduate research experiences will not be offered. The authors called for increased institutional support of undergraduate research, including financial support, support for materials, and other rewards for offering undergraduate research.

Several articles pointed to incentives in the form of reduced teaching or workloads. For example, Wayment and Dickson (2008) mentioned the importance of targeted tactics aimed at faculty including offering incentives and reduced teaching loads via restructuring of course coverage/offerings. Kierniesky (2005) echoed the point that reduced teaching loads could serve as a strategy for increasing faculty availability and motivation to offer and support undergraduate research. The importance of offering reduced teaching loads is also suggested by van Vliet et al. (2013). Shanahan et al. (2017) spoke more broadly to the importance of offering faculty workload credit (i.e. as opposed to just teaching credit) to support faculty engagement with undergraduate research. Schwartz (2012) also suggested supporting faculty via reduction of time constraints (teaching, service) so faculty can offer more opportunities for undergraduate research.

Conversely, Shanahan et al. (2017) suggested that faculty who implement CUREs do this as part of their regular teaching requirements and, thus, receive the workload credit they deserve for promoting opportunities for undergraduate research.

Related to the importance of offering CUREs was a recommendation offered by Spell et al. (2014) that institutions should offer grants for researchers to partner with educators to work together to develop research-based curricula and providing more faculty with professional and curricular development resources.

Several articles more specifically called out the importance of recognition in annual performance reviews and promotion and tenure review. Shanahan et al. (2017) addressed the need for more promotion and tenure credits/time/compensation to support faculty participation in undergraduate research. van Vliet et al. (2013) also highlighted the importance of providing faculty with incentives for mentoring in the form of financial or other awards and recognition in annual performance reviews. Schwartz (2012) pointed to the importance of revising promotion and tenure guidelines to reward undergraduate research mentoring.

In recognizing the importance of faculty motivators, especially for those without external grants and for those early in their careers, Morales et al. (2016) suggested providing supplies for research, faculty summer stipends, teaching credit, conference travel for faculty, and stipends for students doing undergraduate research at other institutions. However, the authors recognized these would be more and less motivating across points in career or discipline and that effective motivational and support strategies will differ across the faculty. Overall, the authors pointed out that, without incentives, fewer students would be able to engage in undergraduate research at other institutions. Finally, Schwartz (2012) highlighted the need to support faculty emotionally to prevent faculty burnout that may arise from challenging mentoring experiences.

Implications relating to broadening undergraduate research participation of students from differing demographics

Eleven articles discussed the importance of broadening participation in undergraduate research across demographics. Several specifically spoke to the importance of addressing assumptions about students with regards to research. For example, Wolkow et al. (2014) pointed to a need to address the assumption held by personnel at two-year institutions that underprepared students are an impediment to innovation in lab courses. Brew and Mantai (2017) also suggested the importance of considering students beyond the academically high-achieving minority for undergraduate research experiences. Similarly, Shanahan et al. (2017) interviewees felt that recruitment of students from historically underrepresented groups, involvement of non-honors students, and enhanced use of communication technologies which beget expanded participation through distance mentoring, must all be prioritized. In Shanahan et al., interviewee's perspectives highlighted the importance of faculty who recognize the worth of students beyond "A" students as potentially sound researchers and the importance of strong mentoring relationships.

Morales et al. (2016) found that faculty who valued diversity were more willing to mentor students from other institutions, which speaks to the importance of educating faculty about the value of diversity in the academy. Morales et al. pointed to the importance of continuing to help faculty realize the potential benefits of mentoring undergraduate researchers towards advancing their own research agendas during the summer and the fact that supporting external summer undergraduate researchers could mean an investment in future graduate students.

Several other articles spoke to the importance of meeting the needs of students from diverse backgrounds as a way to broaden participation. For example, van Vliet et al. (2013) recognized that institutions need to do a significant amount of work to support students from diverse backgrounds. However, the only specific tactic put forth was to diversity the faculty. Schwartz (2012) also suggested that institutions should encourage faculty to be more sensitive and responsive to student needs, especially those of students of color. The authors pointed to the importance of mentoring young students of color. For these students, access to undergraduate research can mean access to transformative experiences and to mentors who are willing to help them navigate a broader range of life challenges than just those related to research (e.g. personal family issues).

In other cases, authors highlighted implications relating to expanding participation in undergraduate research by leveraging these opportunities across institution types, especially within two-year institutions. In Shanahan et al. (2017), interviewees claimed more equitable access is the future of undergraduate research and is obtainable by extending the reach of undergraduate research experiences to a diversity of models, disciplines, and institution types. Wolkow et al. (2014) made the point that students at two-year institutions make up a large proportion of STEM students of color and those living in poverty in the U.S. If we want to engage as many students as possible from historically underrepresented populations in a high-impact practice like undergraduate research, Wolkow et al. (2014) argued that we must make these experiences maximally effective at two-year institutions. Hirst et al. (2014) also pointed out that community colleges enroll a majority of undergraduates today so helping community college students overcome barriers to accessing undergraduate research would have a huge impact on engaging more students in high-impact practices. Spell et al. (2014) found the lowest levels of authentic research occurring in non-major courses, indicating we need to focus efforts of integrating research-based learning into two-year institutions and courses for students without majors.

Kierniesky (2005) extended this idea from the context of two-year institutions to small, liberal arts institutions by highlighting that psychology departments need more resources to support undergraduate research. The authors pointed out that "research activity can demand disproportionate resources at many smaller schools" (p. 85) and argued that more resources are needed in the smaller, less selective schools, in particular, where there is less apprenticeship-style undergraduate research compared to students exploring their own ideas (i.e. a more liberal education model of undergraduate research) and where faculty resources are even more limited.

van Vliet et al. (2013) highlighted the importance of increasing student opportunities for qualitative research as a way to broaden participation in counseling psychology. The authors recommended the creation of a faculty-mentored undergraduate research internship in counselling psychology as a way to create a structure to promote these experiences and suggested employing department-wide coordination of applications and matching.

Finally, while there were no direct implications related to undergraduate research or STEM, Pérez Huber (2010) offered a social justice argument for eliminating barriers to educational access and encourages further research on racist nativism and intersectionality in order to encourage more successful participation of undocumented, Chicana female students in postsecondary education.

Hypotheses

Very few articles were found that present research-supported evidence that barriers to success in STEM postsecondary contexts for students of color manifest as barriers in access to undergraduate research for STEM students of color. We cannot state definitively whether this is because these barriers do not manifest as barriers to undergraduate research or simply because this question has not yet been explored to a significant degree. Yet we suspect that given the nature of the ten categories of barriers to success in STEM postsecondary contexts for students of color highlighted in the results section (see subheading, "*Non-Structured Literature Review*"), barriers experienced more writ large may significantly influence students' access to undergraduate research experiences. Towards informing consideration of those promoting undergraduate research for students from historically underrepresented groups, and to inspire future research on the subject, we propose a collection of specific hypotheses for how these ten categories of barriers could manifest as barriers in access to undergraduate research opportunities for STEM students of color.

1. **A lack of representation at all levels within the college/university, the absence of culturally relevant role models and peers, and being considered to act as a representative of one's group serve as barriers to success in STEM**

postsecondary contexts for some students of color. We hypothesize that some STEM students of color may be discouraged from entering into undergraduate research experiences when their identities are not represented. A student may interpret this lack of representation to mean the research environment is an unwelcoming place for people of color.

2. **Difficulty bridging cultural expectations and norms with expectations and norms in academia, handling conflicting identities, and managing excessive peer/family support or pressure while navigating STEM postsecondary contexts serve as barriers to success in STEM postsecondary contexts for some students of color.** We hypothesize that some students of color may be discouraged from participating in undergraduate research experiences if family obligations and expectations require that students spend more time at home, away from campus.

3. **Exposure to stereotypes, pressure and doubt from self and others, a lack of identity and belonging, and feelings of inadequacy and conspicuousness, in addition to the physical side effects of these psychosocial barriers, serve as barriers to success in STEM postsecondary contexts for some students of color**. We hypothesize that feelings of isolation, alienation, and non-assimilation; a lack of belonging and identity; imposter syndrome; a decline in self-concept; low confidence and self-efficacy; self-doubt; stereotype threat; and stress and anxiety associated with perceptions of difference (as well as the additive effects of these psychosocial phenomenon) may overburden some students and contribute to a decreased likelihood of seeking out an undergraduate research experience.

4. **A lack of access to high-quality academic preparation and a lack of resources prior to college serve as barriers to success in STEM postsecondary contexts for some students of color**. Attending under-resourced schools prior to college could mean that some students of color are not given the tools to earn top grades in rigorous STEM college courses. Because many undergraduate research opportunities are often distributed based on performance in classes (as indicated by Shanahan et al., 2017), we hypothesize that attending under-resourced schools could translate into a barrier to accessing opportunities for undergraduate research.

5. **High financial need and a need to work while in school serve as barriers to success in STEM postsecondary contexts for some students of color**. We hypothesize that this could translate into a barrier to accessing undergraduate research because many undergraduate research opportunities are unpaid, making them unrealistic for students who are more likely to work to fund their college education and/or help support themselves and their families. In addition, students who are working to support themselves may miss opportunities to network with professors (e.g. office hours, review sessions) which could lead to undergraduate research opportunities.

6. **Institutional issues including an unwelcoming campus climate, unsupportive/unempathetic faculty members, and the promotion of competition in some STEM courses serve as barriers to success in STEM postsecondary contexts for some students of color**. We hypothesize that these barriers could translate into barriers to accessing opportunities for undergraduate research. First, perceptions of an unwelcoming campus climate could cause some students of color to avoid calling attention to themselves in and outside of class. This behavior could be interpreted by faculty as a lack of interest in the material and could prevent students from developing important connections with professors that could lead to undergraduate research experiences. Second, the promotion of competition among peers in STEM classes and the perception that professors are arrogant, intimidating, unapproachable, and uncaring may make some students of color feel less comfortable with the prospect of seeking out undergraduate research experiences.

7. **A lack of information about college life and STEM culture or a lack of social/cultural capital serve as barriers to success in STEM postsecondary contexts for some students of color**. We posit that this may translate into a barrier to accessing undergraduate research if students are not informed about the benefits of undergraduate research and how to navigate getting involved in these experiences. Limited awareness of educational policies, procedures, and support programs, which was also highlighted as a barrier to success in STEM during our non-structured literature review, could make it more difficult to find one's way into a research experience.

8. **STEM fields claiming to be objective or neutral in nature serves as a barrier to success in STEM postsecondary contexts for some students of color**. The gendered, raced, and classed history of STEM fields means that barriers to access may exist in the forms of conscious or unconscious biases of professors and deeply rooted institutional and systemic forms of oppression. We hypothesize that the lack of discussions around class, race, gender, ethnicity, sexual orientation, or immigration status in STEM, or barriers related to the intersection of these identities, could distance some students of color from STEM fields and make them less likely to seek out research experiences.

9. **Growing disinterest in STEM or greater interest in another field serves as a barrier to success in STEM postsecondary contexts for some students of color**. We hypothesize that a loss of interest in STEM could be driven by the cumulative effects of other barriers highlighted in our non-structured literature review and that this loss of interest could mean that some students of color feel less inclined to further immerse themselves in their disciplines by seeking out undergraduate research opportunities.

10. **Racism, subtle racialized messaging, and social exclusion serve as barriers to success in STEM postsecondary contexts for some students of color**. We hypothesize that dealing with racism, discrimination, tokenism, stigmatization, exclusion, prejudice and other race-based phenomena could overburden a student and discourage them from seeking out opportunities for undergraduate research, especially if the research is taking place in a space where those phenomena are occurring. We also hypothesize that students who perceive their campus climate to be unsupportive of equity and inclusion might deliberately disengage from any extracurricular activities unrelated to earning their degree in order to avoid additional instances of racism.

Discussion

A Lack of Focus on Barriers for STEM Students of Color

In this article, we present a rigorous, systematic literature review that had the initial goal of examining the extent to which barriers to accessing undergraduate research are present for students of color in STEM programs across postsecondary institution types. We were surprised to find very few articles pertaining to our original research interest; this gap resulted in expanding our inclusion criteria to include articles exploring barriers to accessing undergraduate research, more generally. The 18 articles identified using these expanded inclusion criteria yielded an extensive list of barriers to accessing undergraduate research experiences across disciplines and demographics (outlined in research question #1, above), many of which were not obvious to us when starting this project. Most of these barriers, however, speak to all students and do not focus on issues of access specific to students of color or specific to those in STEM fields.

However, of the 18 articles, one did address specific barriers to accessing undergraduate research experiences for STEM students of color. Schwartz (2012) interviewed black male STEM students and their faculty mentors about the costs and benefits of undergraduate research and found that, while undergraduate research did appear to benefit the students involved, faculty felt that the costs to mentoring outweighed the altruistic satisfaction they received from helping these students. This could mean faculty are less willing to mentor students, which could serve as a barrier to access for students. One faculty mentor lamented that “there is so much need to support our young men of color in the STEM disciplines, so much talk about that need, yet when there is a viable strategy like undergraduate research, there is little institutional support for it” (p. 536). However, this study did not explicitly address barriers to accessing undergraduate research experiences from the students’ perspective.

Pérez Huber (2010) interviewed a student named Carmen who indicated that she was ineligible to participate in state and federally funded undergraduate research programs along with other important campus resources because of her undocumented status. The author attributed this exclusion to racist and nativist immigration policies that prevent certain students from accessing valuable resources, a phenomenon that is likely replicated on university campuses nationwide. However, it was not clear in the article whether this student is studying sciences or social sciences.

We find the overall lack of research exploring barriers to accessing undergraduate research experiences for STEM students of color concerning. We contend that under-exploration of this topic fails to both consider, and attend to, the specific challenges that may preclude students of color from opportunities for these transformative experiences. The gaps in the literature that we highlighted, as well as the hypotheses we offer, may serve as a springboard for future research that, in turn, may help educators and administrators recognize a need for, and means to, promote more equitable access to undergraduate research experiences for students of color in STEM fields.

A Focus on Surface-level Strategies

The authors of the articles we reviewed highlighted a wide range of strategies for overcoming barriers to undergraduate research experiences for students, which may, in fact be of benefit for other stakeholders as well, including faculty members, academic departments, and the institution. These included curricular strategies (e.g. offering CUREs and promoting better/earlier student preparation), strategies related to marketing (highlighting the importance of undergraduate research), strategies regarding clarifying expectations around undergraduate research, and financial and other motivational strategies for faculty participation (e.g. making undergraduate research more cost effective and providing faculty incentives).

Of the 18 articles we reviewed, 11 mentioned implications related to the importance of broadening participation in undergraduate research. Yet we found these offerings to be lacking in detail, overly concise, and not of a critical nature. For example, there were no articles that explicated the importance of helping students of color navigate feelings of racial isolation or institutional and systemic forms of racism that might stand in the way of opportunities for undergraduate research. Instead, most authors engaged in conversations about broadening participation in “nice” ways (as described by Castagno, 2014), for example, by simply suggesting the importance of considering students for research experiences beyond the privileged minority (e.g. Brew & Mantai, 2017) without critically exploring ways to overcome the inequities that may lead to differential access.

Limited use of Theoretical/Analytical Frameworks

Given the relevance of the 18 articles we identified relative to our broader research interests, and in the interest of future research, we were concerned to find a fairly limited use of theoretical/analytical frameworks across the articles. Only five articles employed theoretical frameworks and, of these, only two employed critical lenses (only one of which used the theory as an analytical tool). We contend that employing critical lenses can illuminate potential race-related barriers that may perpetuate differential access to undergraduate research, that may often go unnoticed through the use of theoretical frameworks that reinforce dominant narratives about the majority, as well as insight into remedies. As an illustration, Tucker et al. (2017) claim to contribute to the theory of research preparedness by reporting that student barriers to accessing undergraduate research include not being interested in the work, low confidence to do research, needing more support for preparation, and a lack of research ability. The use of the theory of research preparedness in this article presents two major problems that may be representative of other dominant-narrative frameworks: 1) it may promote deficit-thinking by allowing the placing of “blame” on students for their lack of interest and ability, and 2) it fails to address how individuals may be differentially affected by structures, practices, and systems that influence participation. In this way, the experiences of students from historically underrepresented groups are not specifically considered or attended to, potentially leaving many, or more nuanced, phenomena about access unexplored. We found the use of theories that reinforce dominant narratives, like that in Tucker et al., to be fairly typical across the articles reviewed. By using theories that primarily represent dominant narratives, or by failing to employ a theoretical lens to critically explore relevant realities (as in the majority of studies exploring this topic, e.g. Hirst et al., 2014; Wayment & Dickson, 2008), researchers may fail to illuminate potential race, class, and gender-based issues that may impact students' access to research experiences, and, in turn, are unable to represent the experiences of students of color and allow insight for how to attend to these (Solórzano & Yosso, 2016; Zamudio et al., 2011).

We assert that by employing theoretical frameworks with critical lenses with respect to explicit questions, and appropriate data collection, we might uncover institutional systems and practices that may promote race-based inequalities. Only then can we begin to provide a more complete systems-perspective of relevant societal, cultural, and historical factors impacting undergraduate research experiences, including the voices of those historically underrepresented and silenced in postsecondary STEM. Critical Race Theory is one framework that could be employed more regularly to address issues of access to undergraduate research, as it brings a critical consciousness to the ways in which institutional and systemic racism may affect issues of inclusion in higher education (Solórzano & Yosso, 2002). Other frameworks not specifically considered a critical theory, such as third generation CHAT, may have the potential to encourage researchers to consider and understand multiple perspectives and the mediating factors influencing them (Engeström, 2009). CHAT affords us the ability to focus on *rules, community, divisions of labor,* and *mediating artifacts* that drive action of students, faculty, and the institutions within activity systems concerning accessing undergraduate research. We now revisit our findings within CHAT to further explore existing systems, policies, and practices that could work against, and towards, the goals of promoting access to undergraduate research.

Identifying Contradictions Through the Lens of CHAT

We utilize third generation CHAT (Engeström, 2001), in which both an individual *objective* for each activity system, as well as a common *objective* shared by interacting activity systems, drive action. With respect to our research focus, we conceptualize the *objective* of students' activity system, for those potentially engaged in undergraduate research, to be advancing one's personal and/or professional goals through their participation. We conceptualize the *objective* for faculty, for those potentially supporting undergraduate research, to be advancing one's research agenda via students' work while also contributing to students' professional development. We conceptualize the *objective* for respective organizations, like the institutions where these experiences take place (including academic colleges and departments), to be recruiting, retaining, and graduating competent and employable students while helping to promote the collective success of faculty doing research. Together, these activity systems converge on the shared *objective* of ensuring the prevalence and success of undergraduate research experiences that result in gains for students, faculty, and the institution. We employ CHAT as a framework to understand the *rules, communities, mediating artifacts*, and *divisions of labor* that are relevant for these three stakeholder groups (student, faculty, and institution), that mediate their action toward their own individual *objectives* as well as the common *objective*. In doing so, we identify the affordances for success in facilitating undergraduate research experiences as they relate to each of these key stakeholders. This allows us to not only show which barriers to accessing undergraduate research are highlighted in the literature, but also to suggest strategies for how to overcome them.

Employing CHAT as an analytical framework for this study also allows us to diagnose contradictions within, and between, each stakeholder group (i.e. student, faculty, institution). Diagnosing contradictions is important because contradictions can prevent movement toward each activity systems' individual *objective*, as well as the common *objective* that unites the interacting activity systems, i.e., ensuring the prevalence and success of undergraduate research experiences that result in gains for students, faculty, and the institution. When we use CHAT as an analytical framework to explore contradictions, several noteworthy patterns emerge, including that the barriers to accessing undergraduate research experiences sit at the root of contradictions within and between activity systems (see Figure 3).

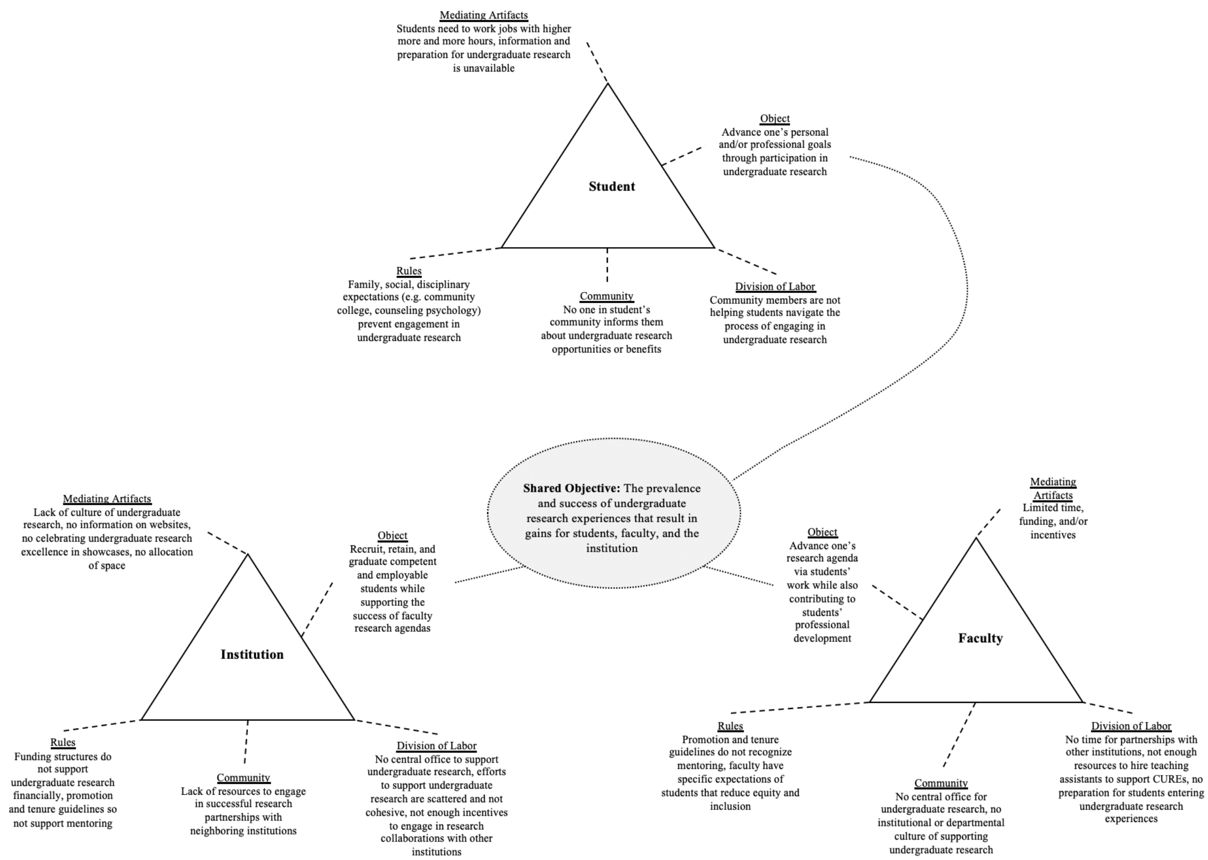

Figure 3. Contradictions *within* student, faculty, and institution-focused activity systems that prevent the achievement of the activity systems' objectives. Contradictions *between* activity systems are characterized within the text.

That is, within the *community*, *mediating artifacts, rules, and division of labor* of each activity system, barriers that we identified through this structured literature review manifest as contradictions that prevent stakeholders from achieving their own *objectives*, as well as the activity systems' common *objective*. For example, if we look closely at *community* across the three activity systems, we notice contradictions at the student, faculty, and institution levels, as well as contradictions between the interacting activity systems, that prevent progress toward the unifying *objective* of ensuring the prevalence and success of undergraduate research experiences that result in gains for students, faculty, and the institution.

Contradictions related to community

First, let us consider contradictions related to *community* within the student activity system. Five articles note student barriers to accessing undergraduate research that relate to a lack of support and/or resources for students on how to navigate undergraduate research, including the lack of an informal system for advertising opportunities (Wayment & Dickson, 2008), the lack of information about directed studies courses (Hvenegaard et al., 2013), and general lack of information about available opportunities for research (Mahatmya et al., 2017). While these generally represent *mediating artifacts*, in the context of CHAT, we contend that they implicate members of the students' community (e.g. academic advisors, program coordinators, directors, faculty members) who are potentially not providing the support/resources needed for students to know how to navigate the process of engaging in research experiences. Without these key players providing information about what undergraduate research is and how to get involved, students are less likely to access these potentially transformative learning experiences, which is directly counter to the student's *objective* of advancing one's personal and/or professional goals through participation in undergraduate research.

Contradictions between *community* and the *objective* of the activity system also emerged for faculty. For example, academics interviewed by Brew & Mantai (2017) note the lack of centralized undergraduate research unit on campus meant efforts to support undergraduate research programs were disjointed and duplicated across campus. Hirst et al. (2014) found that faculty are similarly frustrated by a lack of institutional support and infrastructure to help with things like ordering supplies for undergraduate research activities at the community college level. In both of these examples, key units of the faculty community that could potentially help foster faculty engagement in research experiences for undergraduate students may either be missing or are not organized in a way that is effective toward achieving the faculty's *objective* of advancing one's research agenda via students' work while also contributing to students' professional development.

We also note contradictions for *community* at the institutional level. While it was not explicitly addressed in the articles we reviewed, we know that institutions face various pressures from the public, policy makers, national organizations, and government, to uphold high standards of teaching and research (Atkinson-Grosjean & Grosjean, 2000). In many cases, institutions are accountable to the expectations of these community members. Similarly, institutions look to "isomorphs" (i.e. institutions of similar ranking) as examples of excellence (DiMaggio & Powell, 1991). It is possible that striving to meet expectations of community members with regards to research excellence or competing to meet the standards of isomorphs (e.g. to bring in similar amounts of external research funding, to secure a reputation as a national leader in research) could get in the way of promoting equitable access for undergraduates who are assumed or deemed less prepared and in need of more resources to be a productive and successful undergraduate researcher contributing to a faculty member's research agenda. As such, meeting the expectations and demands of the institution's *community* may present contradictions toward the institution's *objectives* of recruiting, retaining, and graduating competent and employable students while helping to promote the collective success of faculty doing research.

The contradictions outlined above all represent those *within* activity systems. However, contradictions also emerge *between* activity systems. For example, pressure to compete with benchmark institutions and to meet the demands of other institutional community members (e.g. policy makers, the public) could mean an institution is compelled to devote resources to priorities that do not involve undergraduate research, removing a significant incentive for faculty to engage in research with undergraduates. Fewer support staff may be hired to run centralized offices for undergraduate research and to establish or streamline a campus' undergraduate research infrastructure, which might ultimately motivate and help faculty to offer successful research experiences for students.

This contradiction could also extend to impact the *objective* of the student activity system. If institutions are compelled to focus on priorities that do not involve undergraduate research, resources could be drawn away from members of a student's community (e.g. advisors, mentors, instructors) who might otherwise help students learn about opportunities for undergraduate research. That is, if the institution feels pressure to devote resources to priorities other than undergraduate research (e.g. STEM instruction, institutional assessment) fewer personnel could be hired that provide students with important information about experiential learning opportunities or funding for an undergraduate research program could be terminated. By looking at contradictions between activity systems, we can see that *community*-based barriers for students, faculty, and institutions act at the systems level to obstruct the shared *objective* of ensuring the prevalence and success of undergraduate research experiences that result in gains for students, faculty, and the institution.

Contradictions related to mediating artifacts

Next, we consider contradictions related to *mediating artifacts* within, and between, the student, faculty, and institution activity systems. There are several contradictions related to *mediating artifacts* within the student activity system, that ultimately serve as barriers standing in the way of the student's *objective* of advancing one's personal and/or professional goals through participation in undergraduate research. First, as identified by several authors, information about resources and opportunities for undergraduate research serves as an important *mediating artifact* for students' involvement that appears to be missing at some institutions (Hvenegaard et al., 2013; Mahatmya et al., 2017; Wayment & Dickson, 2008). In addition, several articles that we reviewed indicated that students may lack proper preparation to engage in research (e.g. Brew & Mantai, 2017; Hvenegaard et al., 2013; Jones & Davis, 2014). We also found evidence that time and money are missing or lacking, ultimately translating into students' inability to engage in research. Without strategies to properly compensate students for their work, undergraduate research experiences will arguably continue to be more accessible to those who are most financially secure.

Other contradictions related to *mediating artifacts* appear to exist within the faculty activity system, serving as barriers for faculty towards achieving the *objective* of advancing one's research agenda while contributing to students' professional development. Many articles that we reviewed highlight a lack of incentives for faculty to mentor undergraduates, including a lack of financial incentives in summer months (e.g., Hirst et al., 2014; Morales et al., 2016) and lack of compensation for teaching research-intensive courses (e.g., Hvenegaard et al., 2013; Kierniesky, 2005; Perlman & McCann, 2005). Here, faculty incentives are missing as key affordances that could otherwise encourage faculty to engage in research with undergraduates. Faculty time also emerged as an important *mediating artifact* that is missing within the faculty activity system (i.e., ten of the articles we reviewed mention faculty time as a barrier to offering opportunities for undergraduate research). These two barriers (lack of incentives and lack of time) are related in terms of implications and strategies to remedy them; it is possible that faculty could be compelled to devote more time to mentoring students if proper incentives were provided.

Other contradictions related to *mediating artifacts* are relevant to the institution activity system and, ultimately, the institutional *objective* of recruiting, retaining, and graduating competent and employable students while helping to promote the collective success of faculty doing research. For example, Schwartz (2012) found that faculty members felt their institution lacked a vision to support a larger culture of undergraduate research. This lack of culture for undergraduate research implies important supports may be missing that help to increase the potential, efficacy, and visibility of undergraduate research as a prominent institutional structure and practice. Relevant strategies to enhance these things included Wayment and Dickson's (2008) highlighting of the importance of the institutional affordances of hosting a university-wide research conference for students to make undergraduate research more visible on campus. High visibility awards for excellence in mentoring and to honor exceptional undergraduate researchers may also motivate a stronger culture of undergraduate research (Pierszalowski et al., 2018).

Looking at the systems level, we also notice contradictions relating to *mediating artifacts* between student, faculty, and institution stakeholder groups. For example, a lack of institutional culture for excellence in undergraduate research could prevent colleges and departments from feeling encouraged to institute their own undergraduate research programming. It might also mean that colleges and departments do not feel encouraged to ensure specific advisors or other personnel are providing information about research opportunities and resources. Overall, we contend that a weak institutional culture of undergraduate research could trickle down to implicate a lack of college-level or departmental-level emphasis on undergraduate research. This, in turn, could implicate fewer opportunities for students and less of an expectation that faculty will serve as mentors (and possibly fewer incentives for them to do so), which is counterproductive toward achieving to the shared *objective* of ensuring the prevalence and success of undergraduate research experiences that result in gains for students, faculty, and the institution.

Contradictions related to rules

Several contradictions also emerge with regard to *rules* within student, faculty, and institutional activity systems. Based on our findings, contradictions related to *rules* that govern a student's educational experience appear to prevent movement toward the student's *objective* of advancing one's personal and/or professional goals through participation in undergraduate research. The article we reviewed by van Vliet et al. (2013), for instance, indicates there may be implicit *rules* associated with disciplinary expectations that can prevent students from engaging in undergraduate research. In this case, a lack of expectation to conduct research in the field of counseling psychology was put forth as one reason why few students engage in research as undergraduates. We also hypothesize based on the barriers to success for STEM students of color identified through the non-structured literature review that family and cultural expectations may implicate *rules* that prevent participation in undergraduate research for some students. For example, there may be pressure to contribute to the family financially or provide childcare, meaning the student is able to spend less time of campus.

For faculty, implicit *rules* that govern expectations about student competence present a contradiction toward the faculty's *objective*. That is, we reviewed several articles that note faculty perceptions of student capacity and competency serve as barriers to student engagement in undergraduate research (e.g., Brew & Mantai, 2017; Jones & Davis, 2014). If undergraduate research opportunities are only reserved for those with high academic performance and prior experience, we cannot expect to reach the less academically-prepared students who might benefit substantially from participating in undergraduate research experiences. Adhering to implicit *rules* about which students deserve to engage in research based on academic performance and prior research experience is not an equitable approach to distributing these high-impact opportunities and is counter to the faculty's *objective* of advancing one's research agenda via students' work while also contributing to students' professional development.

Two contradictions related to *rules* emerged within the institutional activity system that prevent the achievement of the institution's *objective*. The most notable contradiction emerging from the articles we reviewed is that, in some cases, *rules* governing institutional funding structures do not appear to prioritize undergraduate research. This was implicated in the many articles that highlight a lack of faculty incentives (e.g. Kierniesky, 2005; Perlman & McCann, 2005; Schwartz, 2012), a lack of undergraduate research support personnel (Brew & Mantai, 2017; Hirst et al., 2014), and a lack of financial resources for supplies and student stipends (Brew & Mantai, 2017; Jones & Davis, 2014; Morales et al., 2016; Schwartz, 2012; van Vliet et al., 2013). In addition, *rules* governing the allocation of space on some campuses appear to put space for undergraduate research low on the list of priorities (Hirst et al., 2014; van Vliet et al., 2013). In both instances, *rules* governing institutional structures of funding and space allocation contradict the institution's *objective* of recruiting, retaining, and graduating competent and employable students while helping to promote the collective success of faculty doing research.

Contradictions related to *rules* also exist between activity systems, ultimately leading to conflict related to student participation in undergraduate research. For example, promotion and tenure policies put in place by institutions do not always acknowledge the time faculty spend mentoring students in undergraduate research experiences (Schultheis et al., 2011). Instead, the promotion and tenure process has historically awarded faculty based on excellence in research (e.g. number of publications, amount of external funding secured) and teaching (Hernandez Jarvis, Shaughnessy, Chase, & Barney, 2011). This institutional *rule* has clear implications for faculty. Four articles that we reviewed address the fact that a lack of recognition for mentoring in the promotion and tenure process may prevent some faculty from offering opportunities for undergraduate research (Jones & Davis, 2014; Morales et al., 2016; Schwartz, 2012; van Vliet et al., 2013). Thus, this institutional *rule* also has implications for students, i.e. a lack of faculty recognition for mentoring could lead to fewer opportunities for students to engage in research. The institutional promotion and tenure guidelines introduce a contradiction between *rules* put forth by the institution and the activity system's shared *objective* of ensuring the prevalence and success of undergraduate research experiences that result in gains for students, faculty, and the institution.

Contradictions related to division of labor

Finally, we see contradictions emerge within activity systems that relate to *division of labor,* or what Engeström (2001) refers to as both the implicit and explicit roles of the community members. For students, we again point to the fact that five articles highlight student barriers to accessing undergraduate research that relate to a lack of support and/or resources for students on how to navigate the process of engaging in undergraduate research (Hvenegaard et al., 2013; Mahatmya et al., 2017; Sens et al., 2017; Tucker et al., 2017; Wayment & Dickson, 2008). Overall, it appears as though crucial members of students' university communities may not be effectively helping students navigate the process of getting involved in faculty-mentored research. This lack of targeted support from one's community signifies a contradiction between the *division of labor* and the *objective* of the student activity system, advancing one's personal and/or professional goals through participation in undergraduate research.

We also see contradictions emerge between the *division of labor* and the *objective* for faculty. First, the lack of support and/or resources for students on how to navigate undergraduate research implicates that key players of the faculty's community may not be playing a role in preparing students to engage in research. This lack of student support might ultimately translate into faculty being less likely to engage in research with undergraduates, concerned for their own need to spend precious time and effort to help students reach the point where they are sufficiently able to contribute to research. For example, in the context of CUREs, one participant interviewed in Brew & Mantai (2017) noted they cannot pay tutors enough to sufficiently support students in course-based research experiences without additional support from key community members, i.e., faculty's *objective* of advancing one's research agenda via students' work while also contributing to students' professional development may be impeded.

This lack of community member support is also linked to a contradiction that emerges within the institution activity system in relation to *division of labor*. First, the lack of a centralized undergraduate research office, as noted by interviewees in Brew & Mantai (2017), implicates that key members of the community may not be organized in a way that most efficiently supports student participation in undergraduate research. Also, we see evidence from the articles reviewed that research partnerships between institutions are not being maximally leveraged to promote inter-institutional research collaborations that might expand opportunities for students to engage in research. For example, in the study by Hirst et al. (2014), students and faculty do not feel there are sufficient incentives to engage in research collaborations between two-year and four-year institutions. While we did not find direct evidence for this is the articles we reviewed, it is also possible that peer institutions (i.e. isomorphs) do not sufficiently encourage each other to promote excellence and equity in undergraduate research programming and resources. In the examples highlighted in this paragraph, community members are not filling roles that could help propel institutions toward their *objective* of recruiting, retaining, and graduating competent and employable students while helping to promote the collective success of faculty doing research.

Contradictions related to *division of labor* also emerge between activity systems. For example, the fact that some institutions lack a centralized office for undergraduate research and others fail to devote sufficient resources to hire personnel to support undergraduate research efforts may mean that key community members are not available to help facilitate student-faculty research partnerships. For students, this lack of support personnel could limit the organizational structures in place to help facilitate student participation in research by reducing the encouragement and support students could receive to engage in research, as well as the number of opportunities available. If pathways for students to get involved are unclear, or if students come to faculty with misconceptions about what undergraduate research involves, faculty will need to do extra work and spend extra time preparing students to be successful in research. This added work which could be done by support personnel within a centralized undergraduate research office may cause faculty to be less willing to engage in research with undergraduate students, which inhibits the faculty's *objective*, as well as the common *objective* of ensuring the prevalence and success of undergraduate research experiences that result in gains for students, faculty, and the institution.

Implications

According to Engeström (1987), internal contradictions are "the driving force of change and development in activity systems" (p. xv). By identifying barriers to accessing undergraduate research and mapping the contradictions they introduce onto interacting activity systems, we can begin to visualize ways that transformation can occur. We contend that diagnosing contradictions within and between activity systems highlights solutions to various barriers in the way of participation in undergraduate research, and allows us to consider the relative efforts required by various stakeholders to alleviate such barriers.

Implications for Institutions and Administrators

With insight gleaned from looking at contradictions within and between activity systems, we have identified various implications for postsecondary institutions that vary in their degree of complexity. First and foremost, we recommend that institutions increase the amount of resources allocated for undergraduate research experiences if they want to take advantage of the many gains (including gains in student retention) that students, faculty, and the institution experience by participating in, and supporting, these high-impact practices. Many of the articles we reviewed pointed to a lack of financial resources devoted to supporting undergraduate research, which stood in the way of scaling the number of opportunities available to students (e.g. Brew & Mantai, 2017; Jones & Davis, 2014; Schwartz, 2012). Thus, per our review, we recommend that institutions predominantly focus on allocating resources for faculty incentives, like summer pay and course buyout to address challenges related to a lack of faculty incentives. In addition, we recommend that institutions ensure students receive financial compensation for hours spent conducting research in order to overcome the financial constraints that prevent some students from participating in undergraduate research.

Articles reviewed also highlighted the fact that some institutions lacked centralized infrastructure to support campus-wide excellence and inclusion in undergraduate research (e.g. Schwartz, 2012). This reality translates into a lack of information for students about opportunities, as well as a lack of student preparation to engage effectively in research (e.g. Mahatmya et al., 2017; Tucker et al., 2017). Based on these findings, we recommend that resources be devoted to building centralized institutional or college offices with personnel devoted to helping students learn about and prepare for undergraduate research experiences. We assert that support personnel and centralized programming may elevate undergraduate research activities to be more high-profile as well as easier for students to access. According to Jones and Davis (2014), centralized offices for undergraduate research “are more than symbolic gestures and mailing addresses for [Council on Undergraduate Research] membership materials. Activities sponsored by these offices provide direct training for faculty and students, help connect students interested in undergraduate research with (perhaps interdisciplinary) faculty members, and assist faculty with identifying external funding sources for undergraduate research, among other key tasks" (p. 40). A centralized office could host a campus-wide display of student research or coordinate awards of excellence in mentoring and student research. In addition, having a set of centralized resources may alleviate pressures felt by individual faculty and advisors who are tasked with helping students navigate the process of engaging in undergraduate research alongside various other responsibilities. A centralized unit may additionally minimize duplication of undergraduate research-related resources and spending across campus.

We also recommend institutions consider devoting resources to support the development of CUREs across campus. Research has shown that participation in CUREs may lead to student gains, like a sense of ownership over their research projects and increased persistence in science and medicine (Hanauer, Frederick, Fotinakes, & Strobel, 2012), as well as gains in ability to analyze and interpret data (Brownell et al., 2015). In addition, if presented early in a student's degree, CUREs may have a greater influence on a student's career path than research experiences that take place late in a student's undergraduate career (Auchincloss et al., 2014) and may reduce the stresses placed on students when trying to balance coursework with an apprenticeship-style research experience (Rowland, Lawrie, Behrendorff, & Gillam, 2012). Bangera and Brownell (2014) argue that requiring CUREs in introductory-level courses represents a more equitable way to ensure all students have the opportunity to engage in a research experience, which helps guarantee that all students have the same skills that could be transferred to other research experiences, internships, or graduate school.

However, the authors of articles we reviewed highlighted several challenges to the implementation of CUREs, including a lack of specific guidelines and standards for teaching and assessing CUREs (Hvenegaard et al., 2013) and inadequate training for students, instructors, and support staff while CUREs were being implementing (Wolkow et al., 2014). We recommend that institutions help faculty overcome these challenges by providing faculty with professional development incentives to redesign courses with a research component. In doing so, institutions should support mechanisms that connect those with experience implementing CUREs with those desiring help with the process (e.g. possibly through an institution's center for teaching and learning).

While the above implications are potentially impactful, we assert that if institutions are to best support equity and inclusion in ensuring that all students have opportunities for the high-impact practice of undergraduate research, they must move past the more obvious remedies to barriers to participation in undergraduate research (e.g., allocation of financial resources) and attend to more complex structural and cultural challenges discovered via our review of literature.

For example, we call on institutions to revise promotion and tenure guidelines so that faculty recognition is given for mentoring undergraduate researchers from diverse backgrounds. The promotion and tenure process serves as a way for the institution to communicate what type of work is valued. According to Beth Paul, former President of the Council on Undergraduate Research, “tenure and promotion policies are the primary vehicle through which faculty roles are defined, recognized, and rewarded,” (Paul, 2011, p.2) yet few institutions have made explicit the ways in which supporting high-impact practices like undergraduate research are assessed in the promotion and tenure process. That is, many institutions fail to properly articulate the connection between faculty scholarship and undergraduate research, even though both may be valued independently at an institution. We contend that faculty advancement of undergraduate research inherently contributes to all three areas in which promotion and tenure are most traditionally evaluated – teaching, research, and service. However, because undergraduate research mentoring tends to cut across all three categories, it may not be considered to serve as a solid contribution to one category or another. Thus, we recommend that institutions begin to make explicit the ways in which undergraduate research mentoring can be articulated within each key category of the promotion and tenure evaluation process.

Institutions may want to learn from others who have already begun to alter their promotion and tenure guidelines to explicitly recognize undergraduate research mentoring as an integral part of the institution’s mission. For example, within Weber State University’s College of Science, the dossier requires an articulation of how many undergraduate student projects were mentored, how many publications resulted from this work, and whether the undergraduate research experiences influenced the student’s acceptance into graduate school (Vaughan, 2011). At Viterbo University, science faculty are given two credits toward their teaching loads for mentoring a minimum number of students in any given semester to make the link between undergraduate research mentoring and teaching more explicit (Ronnenberg & Sadowski, 2011). Institutions can encourage departments and colleges to allow apprenticeship-style undergraduate research experiences to count as independent study courses, or replace upper division elective credits. This could address multiple contradictions addressed in the previous section by 1) allowing students to continue advancing in their coursework while engaging in research with faculty, 2) reducing barriers for students who cannot afford to volunteer their time to engage in research without financial incentive, and 3) allowing faculty to demonstrate that time spent mentoring more clearly aligns with their teaching effort, as assessed in the promotion and tenure process. However, we recognize these strategies will have different realities at different types of institutions, which is something this paper does not explicitly address.

Another way to make a faculty mentor's contributions to undergraduate research more explicit in the promotion and tenure process could be to devise alternate ways of evaluating the impact of time spent mentoring. Schultheis, Farrell, and Paul (2011) make the point that mentoring of undergraduate research should be formally evaluated, similar to the way courses are evaluated, so that potential evidence of the effectiveness of this work can be clearly articulated in the promotion and tenure process. The authors also put forth the idea that faculty peer evaluation could be an alternate way to assess the effectiveness of a faculty member's mentoring. Similar to the ways in which institutions use peer evaluations of teaching in the promotion and tenure process, peer faculty could attend group research meetings and observe several collaborative research sessions before composing a written evaluation of the mentoring to put forth for review. This peer observer might comment on the ways in which the faculty mentor is supporting the undergraduate's learning and advancement in the field.

While we recognize these changes would require significant realignment of professor incentives and university success measures, we take these suggestions one step further and recommend that any student-based or peer faculty-based evaluations also comment on the ways in which the faculty mentor is promoting diversity, equity, and inclusion as a mentor. Faculty are under increasing pressure to increase productivity in terms of papers published and grants awarded, which draws away from time faculty can spend mentoring students (Hernandez Jarvis et al., 2011). When faculty do invite undergraduate researchers to join their groups, they may feel compelled to serve as research mentors only to those that are most likely to advance the faculty member's research agenda and require the least amount of guidance. That is, faculty are likely to perceive such students to be the highest achieving and most experienced students (i.e. students who perform well in their classes and have previously engaged in research experience). In many cases, such assumptions and practices elevate the privileged and are arguably counter to institutional commitments to support diversity, equity, and inclusion. Ultimately, we contend that making values regarding promotion of equity and inclusion more explicit to faculty throughout their affiliations and promotions at institutions will encourage faculty to expand their perceptions about who should be allowed and encouraged to participate in undergraduate research (a challenge to undergraduate research participation noted by Brew and Mantai, 2017).

Encouraging faculty to involve more diverse students in undergraduate research will require significant structural changes. We recommend that institutions continue to make these values explicit in the faculty hiring process, during faculty recruitment, when new faculty are first being integrated into the institution, and during annual evaluations. Hernandez Jarvis et al. (2011) go so far as to recommend that institutions include wording in job announcements about the expectation that new faculty will develop research agendas that involve undergraduates. The authors also suggest that institutions make the importance of involving undergraduates in research explicit during the hiring process by having candidates meet with undergraduates interested in research and ensuring that candidates are exposed to campus marketing materials advertising research programs, showcases, and students' published work.

We recognize that shifts in institutional processes and procedures take time. However, steps can be made toward building a reputation for research excellence and inclusion by implementing the strategies outlined in this section. In conjunction with these changes, we recommend that institutions use data-driven approaches (quantitative *and* qualitative) to assess the impact of the changes they choose to implement on students, faculty, and the institution. Demonstrating the differential impact of particular policies and programs on students will help the institution see the relative efficacy of effort, and where more effort needs to be expended. This data can also help convey the worth to relevant stakeholders (e.g. other administrators, faculty, parents, funders, policy makers) of encouraging as many students as possible to engage in undergraduate research toward promoting student retention and diversity goals, as well as their (and faculty members') success.

Implications for Individual Faculty Members and Their Colleges, Departments, Societies

Several contradictions arose that implicate changes in behavior for faculty members, and their respective colleges and departments, towards promoting access (and more equitable access) to undergraduate research experiences. Based on these contradictions, we first recommend that faculty make a concerted effort to help students learn about opportunities for undergraduate research and the benefits they may derive from engaging in these experiences. Our review revealed that both a lack of student awareness of the benefits of undergraduate research, as well as students being intimidated by faculty, both served as barriers to accessing opportunities for undergraduate research (Tucker et al., 2017; Wayment & Dickson, 2008). Thus, we recommend that faculty employ tactics that promote empathy when interacting with students, including having patience and being a good listener, in order to reduce the amount of intimidation that students feel when interacting with faculty. In order to promote these changes in behavior, we call on colleges and departments to help faculty understand that not all students feel comfortable engaging with faculty and that some students from historically underrepresented groups may not see themselves represented as major knowledge producers in the professoriate (as noted by van Vliet et al., 2013), which could affect their sense of belonging and inclination to seek out research partnerships with faculty. To promote this awareness and to help build empathy for undergraduates, we recommend that colleges and departments invite esteemed colleagues with cultural capital to give guest seminars or keynote addresses at society meetings that outline the role faculty play in supporting and developing the next generation of diverse professionals in their respective fields.

We also recommend that faculty expand opportunities for undergraduate research experiences that are embedded within the coursework students are already required to take (Bangera & Brownell, 2014). This recommendation is based on our finding that a lack of student time and compensation emerged as contradictions preventing student participation in undergraduate research. For example, in one study we reviewed, Hirst et al. (2014) found that some students opted not to participate in summer research because the stipend available did not equate to what these students could earn at other jobs. Some students cannot afford to spend extra time engaging in volunteer or poorly paid research experiences, meaning these experiences are often reserved for those who are more financially secure. Offering opportunities for undergraduate research as part of a student's regular curriculum allows a student to engage in the research experience without spending extra time outside of required coursework (Bangera & Brownell, 2014). While we feel that agency lies with the faculty to help alleviate this contradiction, this will become easier for faculty if institutions support faculty efforts to develop CUREs, as outlined above.

A second option to ensure that students are compensated for their work is for faculty to leverage Federal Work-Study to fund student-faculty research partnerships. This strategy is low-cost for faculty and offers students a more scholarly alternative for receiving a Federal Work-Study financial award than many food service or desk jobs (Nazaire & Usher, 2015). If neither of these options are available, we recommend that the faculty member explore with the student the option of having their unpaid research hours replace upper division electives. This way, the student may still make progress toward their degree requirements while engaging in research. As a final note, faculty should also remember to always write in funds to hire undergraduate researchers when negotiating start-ups, applying for grants, and during any other opportunity to secure support for their research, notably in high pressure situations where faculty may not remember to consider the promise of working with/supporting undergraduate researchers.

Finally, we recommend that academic colleges, departments, and professional discipline-specific societies help faculty shift their perceptions of which students should be allowed to engage in undergraduate research. This review revealed that faculty perceptions of student capacity and competency sometimes prevented students from accessing opportunities for undergraduate research (Brew & Mantai, 2017; Jones & Davis, 2014). For example, several authors suggested that faculty may be more likely to select undergraduate researchers with better academic performance (Shanahan et al., 2017) and more research preparation (Jones & Davis, 2014; Morales et al., 2016) than those who need additional academic support or who have not been exposed to resources related to research preparation. How do colleges, departments, and professional societies encourage faculty to engage in a shift in deep-seeded practices and perceptions toward considering greater equity and inclusion in undergraduate research?

We recommend that colleges, departments, and professional societies promote this elevated awareness by encouraging faculty to participate in social justice workshops, trainings, or conversations that help them understand important realities like students' potential intersectionality, the difference between equality and equity, and the range and extent of personal challenges that students may experience, which may prevent the achievement of top grades and prior research experience. These trainings may help faculty think more critically about the reasons why some students do not satisfy their more traditional metrics of merit (i.e. top grades and previous research experience). Do some students lack access to supportive mentors and encouragement to prepare for undergraduate research? Did institutional and/or societal barriers negatively impact their academic performance starting in the K-12 system? It is possible that this shift in perceptions of who should be involved in undergraduate research will occur when faculty become aware of the importance of diversifying the institution and diversifying their respective disciplines through these trainings and conversations.

We recognize that faculty have little time to engage in activities outside of those that contribute to research and teaching. Thus, we recommend that college, departments, and disciplinary societies rely on research-supported tactics for encouraging faculty to attend meaningful professional development sessions. These could include imposing extrinsic motivators like pressure through departmental evaluations to improve mentoring and inclusion strategies (Bouwma-Gearhart, 2012) or identifying key, respected brokers that speak across disciplines of social justice and STEM to deliver this content (Bouwma-Gearhart, 2014). Other strategies could include hosting these events during social hours where lunch and/or beverages are provided, promoting peer-based encouragement to participate, having department heads or deans deliver strong messaging that participation in expected, or by hosting such professional development sessions during faculty meetings where attendance is already required.

Once faculty become aware of the importance of supporting equity and inclusion in undergraduate research, we recommend that they rely, instead, on less traditional metrics of merit when selecting undergraduate researchers, including a demonstrable passion for research, curiosity, and dedication to one's studies. That being said, we recognize that the pressures on faculty to excel in research and teaching will remain. Thus, we also recommend that faculty call on graduate students and more experienced undergraduates to play a role in mentoring new students who are still developing the skills required to work more independently in a research environment (Feldman, Divoll, & Rogan-Klyve, 2013; Pierszalowski et al., 2018; Reddick, Griffin, Cherwitz, Cérda-Pražák, & Bunch, 2012).

We realize that faculty will be (understandably) hesitant to accept an undergraduate researcher with no relevant skills or experience. However, we encourage faculty to recognize that expecting that students come in with graduate-level proficiency in research will put many students at a real disadvantage and promote the use of institutional strategies to help them do this. We assert that faculty must move past a deficit perspective of student performance and preparation towards a view of undergraduate research experience as an educational training opportunity for students to develop and hone the skills and tools necessary to excel as researchers (Hunter et al., 2007).

Implications for Educational Researchers

We found very few articles with empirical evidence outlining barriers to accessing undergraduate research for students of color in STEM, as per our original interest. Thus, this review has illuminated the fact that more research needs to be done to determine whether there are barriers to accessing undergraduate research experiences for STEM students of color, beyond the limited evidence found in this review. Specifically, we encourage educational researchers to explore the set of hypotheses put forth regarding potential barriers to accessing undergraduate research for students of color. We recommend that researchers pay particularly close attention to the hypotheses that emphasize potential structural and institutional barriers, as these tend to represent the more complex, deep-seeded challenges that deserve dedicated attention. Specifically, we recommend that educational researchers employ a critical lens to advance research agendas around 1) the ways in which the gendered, raced, and classed history of STEM fields intersect with a student's tendency to engage in research, 2) how perceptions of campus climate influence one's likelihood of seeking out an undergraduate research experience, and 3) the ways in which institutional practices, policies, and procedures may differentially influence students of color in ways that inhibit access to undergraduate research.

Important for researchers with these interests, we also pause to note our difficulty in pinpointing exact conceptualizations or definitions of access in the articles we reviewed. Several articles situated access in relation *to what* being accessed. For example, Morales et al. (2016) considered access in terms of a students' opportunity to engage in research at an institution other than their home institution. Wolkow et al. (2014) conceptualized access as students' opportunities to engage in course-based research experiences at two-year institutions and considered the ineffective implementation of these experiences to be barriers in access. Others conceptualized access generally as *the means through which* it can or cannot be achieved, for example through more equal distribution of information about experiences (Wayment & Dickson, 2008), incentivizing faculty to mentor students (Morales et al., 2016), or through students' negative perceptions of self and faculty (Mahatmya et al., 2017; Wayment & Dickson, 2008). Pérez Huber (2010) focused more on the question of *for whom* access to undergraduate research is granted or denied; i.e. access is more about the realities for undocumented students when compared to realities and experiences for students with citizenship.

Moving forward, we recommend that educational researchers make access an explicit, central focus point when exploring barriers to participation in undergraduate research experiences. Framing barriers to participation in undergraduate research as issues of access and inclusion may help researchers maintain a critical focus when approaching this work. In addition, it may help various stakeholders, including faculty and administrators, understand the serious implications that go along with barriers that remain unexplored.

Conclusions

This article represents a rigorous, systematic literature review with the original goal of examining the extent to which barriers to accessing undergraduate research for STEM students of color across postsecondary institution types have been addressed with peer-reviewed research. However, while this investigation revealed interesting findings with regard to student, faculty, and institutional barriers to accessing undergraduate research experiences in general, we found a lack of research exploring barriers to accessing undergraduate research experiences for students of color, specifically. By leaving this topic unexplored, we contend that scholars fail to consider potential challenges that students of color may face that preclude opportunities for transformative research experiences.

This literature review goes beyond the level of summarizing what is known in the field. Instead, it serves as a meta-synthesis that draws broad conclusions from prior work, offers a critical look at the rigor of research that has been conducted and situates findings within a theoretical framework. This analytical review makes another important contribution to the field by providing a summary that looks broadly across barriers to success and persistence in postsecondary STEM programs for students of color. This summary ultimately prompted us to hypothesize whether these barriers to success and persistence in STEM also get in the way of STEM students' of color access to undergraduate research experiences. In doing so, this allowed us to identify potential gaps in what is known about access to undergraduate research and recommend areas that implicate future research.

Viewing our findings through the lens of third generation CHAT allowed us to identify and diagnose contradictions within and between activity systems that may prevent access to undergraduate research opportunities. In doing so, we were able to point to areas for potential transformation. In alignment with the nature of transformation originally described by Engeström (2001), the implications outlined above have the potential to redefine the collective *objective* from its original state (i.e., ensuring the prevalence and success of undergraduate research experiences that result in gains for students, faculty, and the institution) to one that represents an even broader range of possibilities: creating institutional structures and systems that allow for more equitable access to undergraduate research experiences for all students. With these transformations, we may begin to see easier access to undergraduate research not only for the students who want to engage but lack the time or financial security, but also for the students who are altogether unaware of the benefits of engaging in undergraduate research experiences.

It is likely that those who have been privileged enough to receive sufficient preparation to engage and excel in undergraduate research experiences will have the confidence and encouragement to advocate for additional research-related experiences. During a time when our nation struggles to close opportunity gaps for students from historically underrepresented groups (National Science Foundation, 2018), we feel it is paramount that faculty begin to recognize the undergraduate research experience as a tool to promote equity and inclusion in their disciplines, at the institution, and in society at large. By providing research experiences for students who might normally face barriers to engaging in them, we can help to ensure a more diverse group of individuals has access to the many personal and professional gains shown to result from participation in undergraduate research. This, in turn, will benefit us all by helping to promote social justice and by cultivating the next generation of high-quality professionals that enter the U.S. workforce.

CHAPTER 4 – Student and Faculty Perceptions of Barriers to Accessing Undergraduate Research for Students from Historically Underrepresented Groups in Engineering

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Introduction

Challenges Related to the Success and Persistence of Diverse Students in Engineering

Despite having similar intentions to pursue a STEM degree upon entering college (Higher Education Research Institute, 2010), students that identify as Latin@, Black/African American, and American Indian/Alaska Native still remain underrepresented in U.S. science and engineering bachelor's degree programs when compared to their college-aged majority-group peers (National Science Foundation, 2018). Scholars have reported that the field of engineering, in particular, has suffered from a "diversity problem" (Chubin, May, & Babco, 2005, p. 73). This is implicated in higher education reports on undergraduate success and retention. For example, a national survey of higher education institutions, the American Society for Engineering Education (ASEE) found that in 2016 only 3.9% of engineering bachelor's degrees were awarded to students identifying as Black or African-American, 10.7% were awarded to students identifying as Hispanic, and 63.4% were awarded to students who identified as white (Yoder, 2017).

This underrepresentation in engineering has been shown to contribute to feelings of marginalization and other challenges associated with navigating an unwelcoming academic climate, all of which influence one's ability to thrive personally and professionally in higher education (Foor, Walden, & Trytten, 2007). It is also important to point out that, for some students, the intersectionality of underrepresented identities (e.g., gender, class, sexuality) can amplify the effects of marginalization and make the navigation of engineering programs even more difficult (Ong, Wright, Espinosa, & Orfield, 2011).

Promoting equity in engineering is important for several reasons. First, people from diverse backgrounds tend to come with a wide range of problem-solving perspectives and strategies. In fact, Page (2008) drew on heuristics, individual interpretation, and predictive modelling to demonstrate how groups of people that vary in perspective tend to outperform those with similar backgrounds. By failing to consider and promote more means for equity in higher education contexts, we risk excluding those with high potential from the pool of future STEM practitioners. This is especially important as our societal problems become more global and increasingly complex. Second, by encouraging the creation of diverse communities of researchers, we also have the potential to counteract biases that limit scientific processes when research teams are homogenous (Intemann, 2009). Many researchers and policymakers also argue the lack of diversity in STEM poses a threat to global competitiveness and U.S. national security (Hurtado, Cabrera, Lin, Arellano, & Espinosa, 2009; President's Council of Advisors on Science and Technology, 2012; Valla & Williams, 2012).

As well, a lack of diversity in engineering has important social justice implications, given that the prosperity associated with many engineering careers is currently reserved for white, male engineers who dominate this field. We concur with Intemann (2009) who argued that we must ensure "the distribution of social goods attached to, and produced by, scientific practice and knowledge be equitable to all citizens, and not merely for the benefit of privileged groups" (p. 250).

The Undergraduate Research Experience as a Tool to Promote Student Success

For decades, scholars have demonstrated the value of participating in research as undergraduate students toward promoting student success and persistence (Bauer & Bennett, 2003; Campbell & Skoog, 2008; Gilmore, Timmerman, Vieyra, Feldon, & Maher, 2015; Gregerman, Lerner, Hippel, Jonides, & Nagda, 1998; Kinkel & Henke, 2006; Lopatto, 2007). In this study, we define undergraduate research as an experience where an undergraduate works with a faculty mentor to explore via inquiry a specific topic of interest in one's discipline. Various types of undergraduate research experiences have been defined (NASEM, 2017). One of the most common is the apprentice-style model of undergraduate research, in which a student works closely with a faculty mentor to investigate a question relevant to a discipline outside of the classroom (e.g. Hunter, Laursen, & Seymour, 2007). In some cases, these types of undergraduate research experiences are initiated through organized undergraduate research programs, which are often cohort-based; have explicit deadlines, requirements, and application guidelines; and are separate from a student's coursework. It is also possible for students to initiate apprentice-style undergraduate research experiences independently of organized programs. This process can be more challenging for some students because it lacks a formal structure (i.e. there are typically no deadlines, requirements, or guidelines to follow). A second type of undergraduate research experience, the course-based research experience, is known to be more inclusive, as coursework is a guaranteed part of the college experience and there is less potential for differential access (Bangera & Brownell, 2014;

Pierszalowski, Vue, & Bouwma-Gearhart, 2018). However, because our study explores potential barriers that students experience when trying to access undergraduate research, we primarily focus on experiences that occur outside of the classroom.

Undergraduate Research as a Tool to Promote Success and Persistence of Students of Color

Our study is centered around the experiences of students of color, which the National Science Foundation defines as students who identify as Black/African American, Latin@, Native American/Alaska Native, and/or Pacific Islander/Native Hawaiian. Recently, researchers have begun to shed light on the benefits of undergraduate research experiences specifically for students of color. For example, studies have reported that undergraduate research experiences help Hispanic and African American students increase confidence (Thiry & Laursen, 2011) and create opportunities for women of color to develop science identity (Carlone & Johnson, 2007). Other studies have found that participation in undergraduate research can increase retention rates for Hispanic and African American students (Jones, Barlow, & Villarejo, 2010; Nagda, Gregerman, Jonides, von Hippel, & Lerner, 1998). Slovacek, Whittinghill, Flenoury, and Wiseman (2012) examined an undergraduate research program for students historically underrepresented in STEM and found that, when compared to non-participants, those involved in the program were more likely to graduate with a science degree, were more likely to enter a science graduate program, and graduated faster with higher GPAs.

These findings are especially important at a time when our country struggles to address disparities in STEM success and participation in higher education. Given the fact that scholars have provided evidence that undergraduate research experiences have the potential to serve as a tool to promote success and retention of students from historically underrepresented groups in STEM, we argue that educators should ensure these opportunities are widely and openly available to students from these demographics. In order to best do this, educators must understand any potential barriers that students from historically underrepresented groups may face when trying to access opportunities for undergraduate research, and relevant strategies that can help to remedy these barriers.

Unfortunately, very few studies have explored whether STEM undergraduates from historically underrepresented groups experience barriers when trying to engage in research with professors. In a rigorous, systematic literature review Pierszalowski et al. (in prep) only identified one article that examined barriers to accessing undergraduate research for STEM students of color. In this one study, Schwartz (2012), via interviews with black male STEM students and their faculty mentors concerning undergraduate research experiences, documented that costs to mentoring outweighed the altruistic satisfaction faculty felt in mentoring these students. Yet this study did not explicitly address barriers to accessing opportunities for undergraduate research from the students' perspective. Instead, interviews with students revealed that students experienced personal and professional gains from participating in undergraduate research.

The Current Study

Thus, we contend that more work needs to be done to elucidate whether STEM students of color experience barriers when trying to access opportunities for undergraduate research. In this paper, we detail an exploratory study examining engineering students' and faculty perceptions of barriers to accessing undergraduate research opportunities for students of color, alongside the selection criteria and processes faculty employ when selecting undergraduate researchers, and student perceptions of these criteria and processes. We additionally explore how faculty and student perceptions and experiences align with respect to these questions as possible disconnects between relevant stakeholders, in themselves, could serve as significant barriers to accessing opportunities for undergraduate research. Results from this study indicate that students from groups historically underrepresented in engineering may experience unique barriers to accessing undergraduate research and that a partial disconnect exists between the selection criteria that faculty use to select undergraduate researchers and students' perceptions of these criteria. Drawing on our findings and our theoretical framework, we put forth implications for students, faculty, and administrators that may help promote more equitable access to undergraduate research, including supporting the development of student agency and breaking down the meritocratic perception that academic achievement is always a significant criterion for participation in undergraduate research. In illuminating potential barriers that engineering students of color face when trying to access opportunities for undergraduate research, we hope to inspire faculty and administrator actions towards access to opportunities for undergraduate research for all students.

Theoretical Framework

Critical Race Theory (CRT) is a framework used in the social sciences to explore issues related to race, gender, class, sexuality, and bases for institutional and systemic racism that, per our research focus, may influence the educational experiences of students of color (Solórzano & Yosso, 2002). CRT assumes the ontological belief that our world is shaped by a struggle for power that dichotomizes privilege and oppression. Sólorzano and Yosso (2002) highlight five tenets of CRT in the field of education. First, CRT highlights the fact that race and racism are connected with other forms of subordination, including class and gender discrimination. Second, CRT challenges dominant ideologies (e.g. the idea that everyone has equal access to opportunities) that perpetuate misconceptions that our educational affordances impact all students in identical ways (Pérez Huber, 2010). Third, CRT emphasizes the importance of promoting critically-informed action to foster positive social change for all students, especially those potentially experiencing oppression (Zamudio, Russell, Rios, & Bridgeman, 2011). As such, CRT can be said to motivate practice (and recommendations concerning practice) towards educational equity and social justice. Fourth, CRT stresses the significance of experiential knowledge, participants' lived experiences, to explore racial inequality. Lastly, CRT highlights the historicity and contemporary contexts of social justice issues and favors transdisciplinary perspectives in exploring these. This theoretical framework provides a lens through which to explore how the polarization of privilege and oppression is influenced by race, ethnicity, gender identity, sexual orientation, ability, and socioeconomic status (Lincoln, Lynham, & Guba, 2011).

In this study, we utilize CRT as a lens to uncover potential race-, gender-, and class-related barriers for students from historically underrepresented groups in STEM that may perpetuate differential access to undergraduate research, a potentially transformative educational experience. We are inspired to use this framework as these realities may go unnoticed through the use of other theoretical frameworks that reinforce dominant narratives about majority experiences (e.g. frameworks like communities of practice and legitimate peripheral participation that do not explicitly call attention to issues of access and inclusion in relation to power, privilege, and oppression). CRT allows us to bring attention to social problems that may remain invisible or underexplored through other frameworks (Lincoln et al., 2011).

Methodological Approach

Research Tools and Methods

In this study, we explore perceptions and experiences of engineering professors and engineering students of color with regards to accessing opportunities for undergraduate research at one four-year public university in the Northwest U.S. with a Carnegie classification of “highest research activity” (The Carnegie Classification of Institutions of Higher Education, 2019). Data presented in this article are from individual interviews with seven engineering professors who have engaged in undergraduate research experiences as mentors and seven students of color in engineering. Research participants and programs unique to the university of this study were given pseudonyms to ensure anonymity. We developed a semi-structured interview protocol in order to allow for flexibility in participant responses when responding to questions relating to undergraduate research (Ritchie, Lewis, & Elam, 2003). CRT informed our decision to conduct semi-structured interviews because this method can elicit in-depth, rich descriptions of a participant's experience, which speaks back to the significance of illuminating participants' experiential knowledge, a central tenet of CRT (Gaxiola Serrano, 2017; Solórzano and Yosso, 2002). It was made explicit to research participants that interview questions referred to undergraduate research experiences that took place outside of coursework. See Appendix E for our interview protocols.

Interviews ranged from thirty minutes to one hour and were recorded and transcribed verbatim for analysis. The lead author first performed data segmenting, as described by Gee (1986), guided by the research questions framing the study, via a codebook using *Dedoose* version *8.0.35* qualitative software. The first author then employed thematic content analysis, as outlined in Auerbach and Silverstein (2003), to identify emergent themes from the data. The second author independently coded ~15% of transcripts and no interrater issues were noted. We employed respondent validation, or member checking, to ensure participant responses were properly interpreted and researcher bias was kept to a minimum (Maxwell, 2013). That is, all respondents were given the opportunity to review and comment on conclusions drawn from their data. By including direct quotes from participants in the final product, we attempted to more accurately represent the individual experiences of participants, in line with CRT (Solórzano & Yosso, 2002).

Qualitative Research Questions

We draw on a phenomenological approach to understand both engineering professors and students' experiences with, and perceptions of, access to undergraduate research. Phenomenology is a qualitative approach used in educational research that aims to describe one's lived experiences concerning a specific phenomenon, including an exploration of one's perceptions, feelings, and understandings of the phenomenon under study (Creswell, 2013). We use this approach to better understand students' access to undergraduate research, guided by the following research questions:

- RQ1. What barriers do professors think students from historically underrepresented groups in engineering face when trying to secure undergraduate research positions?
- RQ2. What selection processes and criteria are used by professors when selecting undergraduate researchers to join their teams?
- RQ3. What barriers do students from historically underrepresented groups in engineering face when trying to secure undergraduate research positions?
- RQ4. What selection processes and criteria do students think professors use when selecting undergraduate researchers to join their teams?
- RQ5. Is there alignment between faculty and student perceptions of access to undergraduate research for students in engineering and, specifically, for students from historically underrepresented groups in engineering?

Participant Characteristics

Seven engineering professors were interviewed for this study. Richard Smith had mentored about ten students over the course of five years. At the time of the interview, he was actively mentoring three undergraduates. One of these students was in the Honors College and all three were from groups historically underrepresented in engineering. One student started working in his lab through an organized program. Richard identified as white/Caucasian and did not feel that any of his identities (e.g. childhood socioeconomic status, gender identity) were underrepresented in engineering. Richard added that the persons an undergraduate researcher worked most closely with in his lab (e.g. a post-doctoral student, a graduate student, another undergraduate, or the professor) depended on the specific project the student was working on but that he typically teamed undergraduates with a graduate student mentor.

Mark Allison had mentored about twelve students over the course of four years. At the time of the interview, he was actively mentoring four undergraduates. At least two of these students were in the Honors College and at least two were from groups historically underrepresented in engineering. Two of them started working in his lab through an organized program. Mark identified as white/Caucasian and did not feel that any of his other identities were underrepresented in engineering. Mark indicated that undergraduate researchers mostly work directly with him but that a few had worked most closely with a graduate student.

Arthur August had mentored about twenty-four students over the course of nine years. At the time of the interview, he was actively mentoring three undergraduates. None of these students were in the Honors College and at least one was from a group historically underrepresented in engineering. All three students started working in his lab through an organized program. Arthur identified as white/Caucasian and did not feel that any of his other identities were underrepresented in engineering. Arthur indicated that students in his lab most often worked under the mentorship of a graduate student.

Colin Williams had mentored about twenty-five students over the course of eight years. At the time of the interview, he was actively mentoring about five undergraduates. None of these students were in the Honors College and two were from groups historically underrepresented in engineering. One student started working in his lab through an organized program. Colin identified as white/Caucasian but felt that his identity as “international” was underrepresented in engineering. Colin added that undergraduates in his lab worked most closely with graduate students 90% of the time.

Abby Banitas had mentored about eighteen students over the course of ten or eleven years. At the time of the interview, she was actively mentoring four undergraduates. None of these students were in the Honors College and at least three were from groups historically underrepresented in engineering. None of her current students had started working in her lab through an organized program. Abby felt that she was underrepresented in engineering because she identified as female and did not identify as white. When asked if undergraduates worked under her mentorship or under the mentorship of a postdoctoral student, a graduate student, or other undergraduates, Abby replied, “all of the above.”

Malia Bradshaw had mentored about seventeen students over the course of two years. At the time of the interview, she was actively mentoring ten undergraduates. Two of these students were in the Honors College and nine were from groups historically underrepresented in engineering. Most students had started working in her lab through an organized program. Malia felt that she was underrepresented in engineering because she identified as female, “international,” and as a first-generation college student. Malia added that the person an undergraduate researcher worked most closely with in her lab depended on the specific project the student was working on.

Noah Garrison had mentored between thirty-five and forty-five students over the course of nine years. At the time of the interview, he was actively mentoring seven undergraduates. At least one of these students was in the Honors College and about six were from groups historically underrepresented in engineering. Two students started working in his lab through an organized program. Noah identified as white/Caucasian but added that he came from a low socioeconomic status background. Noah indicated that students in his lab most often work under the mentorship of a graduate student. All but two professors had only mentored undergraduates at the university of our study; Abby and Noah mentored students at the university of our study as well as institutions at which they worked previously.

Seven students were interviewed for this study. Ethan Clark identified as Hispanic, as a first-generation college student, and as a transfer student. Ethan had participated in undergraduate research before. He got involved in undergraduate research during his first year at the university as part of the STEM Diversity Program, which he learned about during his transfer orientation session. He continued his involvement in undergraduate research in the same lab even after participating in the STEM Diversity Program.

Cindy Cole identified as white and Native American and as a first-generation college student. Cindy had participated in undergraduate research before. She identified a professor in a STEM field outside of engineering to work with as part of her preparation to apply for a campus-wide undergraduate research program, the Undergraduate Research Scholars Program. She heard about the program though digital marketing boards in the engineering department and from friends who were also applying. Cindy and the professor applied together and, because she started volunteering in the lab before she found out she did not receive the award, the professor decided to hire her as a part-time student employee. While she did not end up participating in undergraduate research as part of the Undergraduate Research Scholars Program, the program did serve as the impetus for her to make the connection with the professor she did end up working with for over two years.

James Zimmerman identified as black/African American, Ethiopian, and Japanese. James had participated in undergraduate research before. James got involved in undergraduate research during his first year at the university as part of the STEM Diversity Program, which he learned about it during his involvement in a summer bridge program for STEM students of color. James later engaged in a second undergraduate research experience through another organized program for engineering students.

Emily Wright identified as Pacific Islander. Emily had participated in undergraduate research before. Like James, she learned about opportunities for undergraduate research during a summer bridge program for STEM students of color, which "heavily emphasized" the idea of participating in undergraduate research. After the bridge program, a professor came to talk about her research in one of Emily's courses. Emily emailed the professor to set up a meeting to discuss the research further, as she was instructed to do during the bridge program. Emily was then invited to engage in research with the professor. According to Emily, "… if I hadn't done that bridge program, I honestly don't think that I would know that research is available for students or that it's something that professors want students to engage in."

Michael Williams identified as Alaskan Native and as a transfer student. Michael had not participated in undergraduate research before and had never tried to access an opportunity, even though it was something he was interested in doing as an undergraduate. Michael was interested in participating in undergraduate research because he felt that getting research/field experience would help him advance his career. He did indicate that he had looked at faculty and their research interests in the past and planned on trying to find an opportunity but had not yet.

Tony O'Neil identified as European, Hawaiian, Japanese, Chinese, and Native American; and as a transfer student. Tony had not participated in undergraduate research before and had never tried to access an opportunity, even though it was something he was interested in doing as an undergraduate. Tony was interested in participating in undergraduate research because it sounded fun and exciting. He completed his first two years at a community college while working throughout and focused primarily on coursework without getting involved in activities outside of class. His reasons for not trying to access undergraduate research were that he did not have time because of work and because he had only just started his first course at the university of this study online when the interview took place (i.e. he had not yet taken classes on campus). He looked forward to having opportunities like undergraduate research at a university.

Karina Sanchez identified as Hispanic/Mexican and as a first-generation college student. She also noted that she identified as a "lower income student," which also made her underrepresented in engineering. Karina had not participated in undergraduate research before. She had tried to access an opportunity for undergraduate research before but was unsuccessful.

Results

Results are presented under our research questions and are related to the specific pertinent interview questions posed to the research participants.

RQ1. What Barriers do Professors Think Students from Historically Underrepresented Groups in Engineering Face When Trying to Secure Undergraduate Research Positions?

Does everyone in engineering have equal access to undergraduate research?

Some faculty felt that all students in engineering have equal access to undergraduate research, while others did not. Malia was certain that not all students have equal access. She indicated that having a certain personality type, like being shy and not talking to the right people, could mean some students have trouble accessing undergraduate research. Richard indicated that because engaging in undergraduate research is “incredibly ad hoc right now,” he felt it may be especially challenging for students that are shy or lack confidence to access these experiences. He worried that this meant there was an entire demographic of talented students who faculty do not engage with.

Colin also seemed certain that not all students have equal access to undergraduate research since faculty often do not communicate about opportunities for participation. Both Mark and Richard addressed the fact that there are not as many undergraduate research opportunities available as there are students interested, which meant not everyone was able to participate. Noah felt that, hypothetically, every student could apply for various programs and seek out faculty mentors but he added that economic status made it so there was not equal opportunity for all students, i.e. he noted that not everyone had parental support to pay for college and some students had limited access to undergraduate research because they could not afford to volunteer to engage in these experiences. Mark indicated that there may be more barriers for students who do not get engaged in programs targeted for early career students due to a lack of formal undergraduate research programs for students later in their college careers (i.e. past the second year), meaning these students would have to network on their own, which could be more challenging. Mark went on to explain that students do not always realize that faculty engage in research in addition to teaching courses, which can mean faculty become too busy to respond to email. He noted that some students may interpret a lack of response to email as an outright rejection (as opposed to a professor forgetting to respond, for instance), causing them to give up their search for research experiences.

Both Noah and Richard indicated that there are actually *more* funded opportunities for underrepresented students. According to Richard:

> I mean honestly there's more opportunities, more different sort of funding opportunities for underrepresented students. I don’t know if, they're already under representative, but that's just the reality like I get pots of money that are only can really use for certain students and I can't comment on what my colleagues do, but it is harder sometimes to carve out sort of general funded positions within grants for just for any [student].

When asked about access for students who would be willing to just volunteer (not be paid for their work), Richard indicated that there is probably equal access if a student demonstrates willingness or interest.

Arthur felt that all students do have equal access, at least per the way he approaches recruitment, as he tries to convey the same information about available opportunities to all students. He indicated, however, that it is possible that some professors operate differently, and are more likely to “hand pick who they want.” We interpreted this to mean that some professors are more inclined to select students based on certain characteristics, which could mean there was not equal access to research opportunities for students not possessing these characteristics. It was Abby's perception that most faculty are willing to engage students in undergraduate research. However, she did not elaborate on whether this meant faculty are willing to engage *all* students in research, or just those who professors perceive will most significantly advance their own research agendas. She was not sure whether all students have equal access to undergraduate research but indicated that she personally tries to make access easy for all students.

General barriers for students in engineering

While there may be some overlap of ideas between this section and the previous one, we choose to keep them separate as they were framed as two different research questions to participants. Five professors (Malia, Arthur, Noah, Colin, Abby) indicated that a lack of access to information served as a general barrier to accessing undergraduate research for students in engineering. Malia, Arthur, and Colin felt this could have to do with a lack of advice and communication from faculty to help students understand that research opportunities exist. Noah felt this was particularly true for transfer students, claiming that many faculty members assume transfer students will already know how to navigate opportunities for undergraduate research when they arrive to the university. He said, "transfer students in engineering get lost a little bit, because they're not here for those first two years when we really put a lot of effort and energy into trying to make our students successful."

Several professors also pointed to barriers that relate to faculty perceptions of working with undergraduates. Arthur indicated that some professors in engineering are hesitant to involve undergraduates in their research because they do not see the value in it. Richard also indicated that some faculty emphasize transactional relationships with students and would not consider taking a first-year student or someone who could not contribute to their productivity from the beginning. Mark added that it can be difficult for faculty to make their research approachable to undergraduates. He said, “the projects that I give students have to be made very low barrier, because, I, most the time, you know, they don't have, if they're first and second year, they got nothing.” Richard believed that faculty capacity was a barrier since there were more students interested in engaging in undergraduate research than faculty who could mentor students.

Malia, Richard, and Noah pointed to a need for some students to work while in school as a barrier to participating in undergraduate research. Another general barrier mentioned by Richard was a lack of formal infrastructure for undergraduate research, which meant that not all students had opportunities. Richard also indicated that a lack of faculty incentives could serve as a barrier to student participation in undergraduate research. While he indicated that he does enjoy mentoring undergraduate researchers, he views mentoring as extra work. According to Richard, allowing undergraduate research to count toward a student’s degree requirements could encourage faculty to serve as mentors. This is because the mentor would not have to worry about paying the student since the student would still be benefiting from the experience by gaining course credit.

It was not clear to Richard whether/how faculty are typically rewarded for mentoring undergraduate researchers. He recognized that more faculty might be encouraged to mentor more undergraduate researchers if it was a more explicit aspect of their evaluation, especially because faculty time is so limited. He said:

> I'm an assistant professor, so at the end of the day, um, how am I judged in my tenure and promotion? Undergrad advising does show up on the sort of tenure dossier, but… it's not clear like you know I don't think you're only going to get tenure by just advising a million undergrad students.

Finally, Abby brought up the point that the course load in engineering is so heavy, students may have a hard time balancing a full course load with the additional responsibilities of participating in undergraduate research, unless they are taking undergraduate research for elective credits that count towards their degree.

Barriers for students of color in engineering

Five professors expressed some uncertainty about whether there were unique barriers to accessing undergraduate research for students of color. Richard felt he did not have enough experience working with students of color to answer but did indicate it was possible that some students of color may need to work while in school and would not be able to engage in undergraduate research for little or no pay. Mark did not think there were barriers for students of color with regard to accessing undergraduate research through formal channels like organized undergraduate research programs. Abby admitted it was hard for her to think about whether students of color face challenges because she felt that there were no challenges for students trying to enter her own lab. She wondered whether implicit bias on the part of some faculty members might serve as a barrier, as well as whether some female students of color from “conservative countries” may not feel comfortable working on a research team with colleagues of another gender. Colin added that an overall lack of students of color in engineering could mean there was no cohort which could otherwise provide peer support to engage in undergraduate research. Other than that, he was not sure whether there were unique barriers impacting students of color. Arthur first indicated in the interview that it was hard to say whether students of color faced any barriers to accessing undergraduate research. He later articulated that hesitation on the student’s part may be a barrier, elaborating that students of color may feel “imposter syndrome,” that could prevent them from getting involved in undergraduate research. He also indicated that students of color may find it difficult to integrate into a lab group that is mostly comprised of people who identify as white and that a lack of role models may be a barrier.

Malia was more certain than others that students of color face unique barriers when trying to access undergraduate research. She admitted to personally knowing students who experienced social exclusion and microaggressions that she believed could have made them more reserved in terms of personality, which could have made them less likely to seek out opportunities for undergraduate research. She also indicated that being a student of color may intersect with being a first generation or low-income student, the confluence of which could lead to additional barriers; yet she admitted that such realities were beyond her area of expertise and, thus, that she was not confident in her thoughts. Noah also pointed to the fact that income inequality disproportionally affects students of color and, thus, that economic issues might serve as barriers to accessing undergraduate research for these students. Noah and Richard both mentioned that faculty bias and discrimination could serve as a barrier, although Noah admitted that he was not personally aware of any instances of this. Arthur also added that he was not certain whether there was overt discrimination by those selecting students for undergraduate research based on race.

Mark indicated that some students of color may not have social networks in engineering, explaining that this could be a barrier to undergraduate research as some students enter his lab/UR experiences through social connections with other students who have worked with him. Mark went on to elaborate that he intentionally seeks out students of color through networks in which they may belong, like campus diversity programs, but recognized that it was unlikely that all professors make a habit of this. These barriers, as well as those mentioned by students and faculty for other historically underrepresented groups, are summarized in Table 1.

Table 1

Barriers to Accessing Undergraduate Research Experiences for Various Underrepresented Groups Highlighted by Students and Professors in Engineering

Demographic	Faculty	Student
Students of color*	-lack of role models -need to work while in school -implicit bias/discrimination -lack of cohort of students of color	-lack of role models -lack of belonging -lack of awareness about opportunities

	-not wanting to work/difficulty working in a research team dominated by people whose identities do not align with yours -student hesitation -imposter syndrome -social exclusion/microaggressions could make one more reserved -lack of social networking/connections -barriers related to other intersecting identities -economic issues/income inequality	-lack of family support when navigating undergraduate research -lack of time -lack of money/lack of financial support of family -family dynamics/social upbringing
Women	-lack of role models -lack of confidence -underrepresentation -self-criticism -culture of masculinity/intimidation from male-dominated research teams -not considering undergraduate research	-lack of role models -lack of confidence -underrepresentation -discrimination -no sense of belonging -increased competition
Students identifying as LGBTQ+	-hesitations about accessing undergraduate research per feeling different from the "norm" -fears about not being welcomed -underrepresentation -general challenges associated with not "coming out" -society might make them more reserved -microaggressions -social exclusion -not feeling welcomed	-lack of role models -faculty bias and discrimination -feeling intimidated by faculty -not comfortable/confident approaching a professor because of feelings of isolation/lack of support system
First-generation college students	-lack of emotional/professional support from family -not hearing family stories about college life -less family expectation to engage in undergraduate research -lack of family encouragement to seek out undergraduate research -lack of help from family/the institution to navigate undergraduate research	-lack of role models -may not have family members who can help them navigate college, including opportunities for undergraduate research -lack of family connections/family networking -family not aware of value of undergraduate research -not able to engage in conversations about undergraduate research at home

	-general lack of knowledge about opportunities for undergraduate research -being overwhelmed by transition to college -family pressure to get a paid job/focus on grades -parents do not see value in undergraduate research -financial pressures/time constraints	-attended low-income K-12 schools/limited access to educational resources and programs -discrimination -more difficult time in coursework if parents do not have STEM background
Students from low socioeconomic status backgrounds	-have to work jobs with better pay/longer hours -lack of access to computers or K-12 educational resources with computers -no financial safety net	-have to work jobs with better pay/longer hours -attending underfunded high school can make one less competitive and less likely to access to Advanced Placement courses that could save money and time -financially motivated to get through school faster, which can be isolating -lack of access to cell phone/Wi-Fi at home/parking near campus, which can make one less connected to what is happening on campus -having to purchase one's own research supplies
Students who have to work while in school	-lack of time -difficulty balancing work and school -cannot afford to volunteer in a lab -employment elsewhere could mean less time for research	-lack of time -difficulty balancing work and school -cannot afford to volunteer in a lab -inflexibility related to one's other job could make them seem less reliable

Note. Barriers for students of color (*) align with those hypothesized in our systematic literature review (dissertation chapter 3).

Barriers for women in engineering

Malia and Noah both pointed to a lack of confidence as a potential barrier to reaching out to mentors and accessing undergraduate research for women in engineering, especially when compared to male students. According to Malia:

> I think males, not to be stereotypical but generally they are more confident even when they don't know. They think they know. They never say I'm not smart enough. That something I hear a lot from the female students. ‘Oh, I don't think I can do it.’ ‘I don't think I'm smart enough.’ Or whatever. Then I have to keep reminding them that that's not the case.

Noah also stated that female students experience a lack of self-confidence and were more shy and introverted when compared to men. He also felt that female students’ self-criticism of their math ability could serve as a barrier to accessing opportunities for undergraduate research.

Arthur, Mark, Noah and Richard all indicated that female students may face barriers to accessing undergraduate research that relate to the underrepresentation of females in engineering overall. Arthur felt that a lack of female representation in research positions could be a barrier because female students may not see someone like them working in the lab. Noah added that a culture of masculinity in research settings could be a barrier:

> And then there's the culture, too, right? If you're going into a lab that's 90% men, including the PI, the masculinity culture, if you're not careful, can be very, very turnoff-ish. Maybe it's a detriment to the student in that they don't even want to apply to that lab. Right? So, they self-eliminate themselves from certain opportunities, and I've definitely heard stories about that, and from students.

Mark indicated that trying to access research labs that are dominated by men could be intimidating to female students. He also pointed out that some faculty members he knows have relatively large research teams that only consist of male students/researchers and wondered if something negative is to blame for this reality, perhaps not explicit bias but something else that prevents female students from accessing these experiences.

Three professors seemed less certain that there were unique barriers for women in engineering. Richard, for example, indicated there were no unique barriers for women in engineering besides other inherent barriers and biases that exist in the field. When asked to elaborate on what these might be, he said: “Um, I'm a little out of my element here, but just being completely underrepresented, particularly here at [the university of this study], particularly in mechanical engineering, I think there's just inherent issues in that.” Colin did not think there were barriers for women in engineering accessing undergraduate research in his program but said he could imagine that there were barriers or perceived barriers elsewhere in engineering. Abby seemed to interpret this question a bit differently and answered that she thought women in engineering have great chances to do undergraduate research because they are often very organized. She added that the problem was that there are so few female students in engineering that it is hard for her to find women to join her lab. She also indicated that most female students do not think about undergraduate research but did not elaborate on why that was the case.

Barriers for LGBTQ+ students in engineering

Faculty differed in their opinions of whether engineering students identifying as LGBTQ+ face any unique barriers when trying to secure opportunities for undergraduate research. Four professors (Arthur, Richard, Colin, Abby) did not think there were unique barriers for these students, or felt that there were fewer barriers than there were for students from other historically underrepresented groups. Arthur indicated that there would be fewer barriers than for students with more visible forms of underrepresentation (e.g. women and students of color) but added that students identifying as LGBTQ+ might have hesitations about accessing undergraduate research per feeling different from the "norm." Mark indicated that it was difficult to determine whether students identifying as LGBTQ+ face any unique barriers because that aspect of their identity was not always obvious to others. He offered that there could be some bias if their identity was known to others, and that students may have fears about whether they will be welcomed into the research group. Richard did not think there were unique barriers for LGBTQ+ students other than the inherent barriers associated with being underrepresented in engineering overall, yet he did not articulate what these barriers might include. Cindy also did not think there were any unique barriers, but recognized that there may be challenges in general for students who do not come out and identify as LGBTQ+. Abby also did not think there were any unique barriers for LGBTQ+ students but admitted that she could only speak with respect to her own experiences with undergraduate research. Abby spoke about the objectivity inherent in research and how this objectivity should negate any barriers related to identity. She said:

> Research doesn't care who you are, where you come from. It just cares for the idea right? And a great idea and a great creativity could come from anywhere in this universe, right? And it's humans like us who are in the middle, who bring those biases and bring those barriers and constraints, right? But I guess, if you're true to the principle of research, the barriers should not be existing if they do exist, right? So I can only speak for my lab. In my lab, I always try to not think about...That's just me, [inaudible] that's just limited to my own understanding. Those kind of issues are not in my forefront of my mind when I'm making decisions about who to recruit.

Two faculty members seemed more confident that there were unique barriers for students identifying as LGBTQ+. Malia felt that society might affect these students in ways that make them more reserved and therefore less likely to access opportunities for undergraduate research. Noah offered that a lack of acceptance from fellow students, including microaggressions and social exclusion, may translate into the student not feeling welcomed at the institution overall, which might translate into a barrier to accessing undergraduate research specifically. This lack of acceptance was something he had personally witnessed at both the undergraduate and graduate levels.

Barriers for first-generation college students in engineering

Faculty identified a number of barriers to accessing undergraduate research that were unique for first-generation college students in engineering. Three professors indicated that a lack of emotional or professional support from family could serve as a barrier to accessing undergraduate research. Arthur felt that barriers were more obvious for first-generation college students than those from some of the other historically underrepresented groups mentioned. Specifically, he indicated that first-generation college students may not have been surrounded by stories of what college life is like and what opportunities are available. In addition, he felt that there may be less of a family expectation to participate in opportunities like undergraduate research. Malia indicated that first-generation college students may not have family members or mentors at home to encourage them to seek out undergraduate research. Abby also felt that first generation college students may not have a personal support system at home when navigating opportunities like undergraduate research and that a lack of added institutional support to help first generation students navigate the process of getting involved in undergraduate research could serve as an additional barrier to accessing undergraduate research.

Four professors indicated that a general lack of knowledge about opportunities for undergraduate research served as a unique barrier for first-generation college students in engineering. Mark noted that many undergraduates are unaware that faculty engage in research and that this may be exaggerated in first generation college students. Richard, Colin, and Noah also added that not knowing undergraduate research opportunities exist could serve as a barrier to accessing these experiences for first-generation college students. Based on his experience, Noah contended that first generation college students are typically more overwhelmed by adjusting to college life than other students and are unsure about how to navigate university resources/programs that might lead to opportunities for undergraduate research.

Two professors pointed to family pressure as a potential barrier to accessing undergraduate research. Mark indicated that first-generation college students may experience family pressure to get a paid job, rather than engage in undergraduate research and pursue graduate school. Noah also indicated that students may feel pressure to avoid extracurricular experiences like undergraduate research that could distract one from maintaining good grades, especially considering the cost of a college degree. Noah added that parents of first-generation college students may not see the value in undergraduate research.

Mark and Richard pointed out that financial pressures and related time constraints could serve as barriers to accessing undergraduate research for first-generation college students in engineering, but indicated that this would be a barrier for all students, including low-income students.

Barriers for engineering students from low socioeconomic status backgrounds

Malia and Richard both felt that students from low socioeconomic status backgrounds in engineering do not have time to dedicate to research because they need to work jobs with better pay. Arthur felt that barriers to accessing undergraduate research for students from low socioeconomic status backgrounds were the same as barriers for first generation college students, but that "they also have an added challenge of, maybe, just trying to survive." He added that students from low socioeconomic status backgrounds do not have a financial safety net so they need to work jobs with longer hours that allow them to earn more money. Abby noted that universities have become increasingly expensive, especially with rising tuition costs and elevated tuition rates for engineering students, so many students have to work to pay for college, cover their loans payments, as well as cover their daily living expenses. However, she asserted that this is a problem for everyone, not just students from low socioeconomic status backgrounds. According to Abby, "when a student is working to survive, and going to school, where are they going to get the time to do research? Where are they going to get the opportunities to explore ideas and creativity, right?" Noah added that barriers to accessing undergraduate research for first generation college students was a topic that deserved more attention.

Mark also felt that students from low socioeconomic status backgrounds face barriers to participating in undergraduate research if the research experiences are unpaid. He added that students from low socioeconomic status backgrounds may have lacked access to computers or may have attended a K-12 school system that did not offer opportunities to become familiar with computers. Mark admitted that he typically looks for students who have skills with computer programming and if students did not have access to opportunities to learn those skills, they would face barriers to engaging in undergraduate research with him. Finally, Colin indicated that while he felt there were "normal life barriers," he did not think there were unique barriers in accessing undergraduate research for students from low socioeconomic status backgrounds specifically.

Barriers for engineering students who have to work while in school

All seven professors indicated that a lack of time was a barrier for engineering students who have to work while in school. Arthur felt this could serve as a barrier from the professor's perspective when hiring a student. That is, he personally looks at whether students have multiple jobs before accepting them into his research team and uses this as an indicator of how much time they will be able to devote to research in his lab. Mark added that it would be difficult to get selected for an undergraduate research position if you could only devote a few hours per week to research compared to a student who could work 10-20 hours per week. Abby more specifically indicated that balancing time between work and school obligations serves as a barrier to accessing undergraduate research. In Abby's words, "You only have 24 hours, you only have one human body." Noah expressed similar concerns and pointed out that unpaid/underpaid undergraduate research opportunities are "really good for the privileged" but not for those who have to work while in school. Colin felt that having to choose between an unpaid undergraduate research experience or a paid job would serve as the primary barrier for students who work while in school. However, he pointed out that he tries to pay all of his students and encourages them to work in the lab instead of working in food service, for example, since it is more productive toward their career goals. Despite concerns about student time as a barrier to accessing undergraduate research, Richard made the point that some students qualify for Federal Work Study program, which makes it much more affordable to hire them for paid positions.

RQ2. Which Selection Processes and Criteria are Used by Professors When Selecting Undergraduate Researchers to Join Their Teams?

How professors recruit

Five professors indicated that they recruit students for undergraduate research experiences, either intentionally or unintentionally, by giving talks about their research in classes. Colin said that when he or his graduate students are looking for an undergraduate, they look up which courses are being taught and give brief presentations at the beginning of those classes. Noah added that he does not typically teach students until they are in their senior year so he and his colleagues have been working on trying to make more appearances in lower-division classes so they can connect with undergraduates earlier in their college careers. Noah also talks to students about his research in Honors College courses. Abby, Arthur, and Malia all indicated that they give talks about their research in the classes they teach and sometimes recruit students this way. Malia, Noah, and Colin mentioned that they sometimes recruit students through outreach events like meet-and-greets and events with faculty panels.

Arthur, Abby, Noah, and Mark all indicated that they recruit students through organized undergraduate research programs. For Abby, this also meant getting connected with students and helping them complete their engineering capstone projects. Four professors (Malia, Abby, Arthur, Mark) indicated that they end up recruiting students via word of mouth. Mark and Arthur, for example, ask their current students to help them find interested undergraduates. Mark asks diversity program coordinators for student recommendations while Arthur asks other faculty or advisors. Abby indicated that she has recruited students using fliers to advertise an opening. One professor (Richard) admitted that he does not really actively recruit students because funds and time are limited. He typically allows the student to make the first move, which has the added benefit of self-selecting students who are willing to demonstrate initiative.

How students let professors know they are interested

All seven professors indicated that students let them know they are interested in engaging in research by reaching out in person (e.g., by stopping by their office) or via email. According to Richard, this usually leads to a meeting to see if the student and professor share mutual interests. Four professors (Mark, Noah, Abby, Richard) indicated that students let them know they are interested in participating in undergraduate research through formal channels. Three of these said this typically happened when students expressed interest via applying for organized undergraduate research programs. Richard added that this was most common for early-career students. The fourth professor, Abby, said that some students let her know they are interested in engaging in research for elective credits, another type of formal structure for engaging in undergraduate research. Three professors (Noah, Richard, Colin) said that students reach out after hearing about their research in the classes they are taking. Richard added that it was more common for older students to reach out this way than through organized programs, since most of the existing programs are reserved for early-career students.

How professors prefer students let them know they are interested in research

Malia, Richard, and Mark indicated that email was their preferred method for communication when students are interested in participating in undergraduate research. Mark added that meeting in person at an event and then receiving a follow-up email from the student is also acceptable. He also added that he likes it when a student indicates in their initial correspondence whether they have a current connection to someone on his research team so that he can ask for a reference. Colin and Abby indicated that they do not have a preference for how students let them know they are interested in engaging in undergraduate research. However, Colin did indicate that he does request a face-to-face meeting before students start working in his lab, even if they are working primarily with a graduate student, so that the student knows they have a faculty member they can rely on.

Arthur said that he prefers that a student approaches him, rather than recruiting a student himself, because it shows they have taken the initiative to identify someone working on something that aligns with their scholarly interests. However, he did not articulate his preference for exactly *how* a student approaches him. Noah felt it was best that students demonstrate interest through intentions to apply for a formal undergraduate research program since these processes tend to come with an established level of rigor and guaranteed funding. It seemed as though this was important for Noah because the application process for a program would ensure any interested students were well qualified and he would not need to secure external funding to compensate the student. For students who want to get involved outside of a formal program, he expects that students would seek him out; he has an "open door policy" for students who demonstrate initiative and interest in his work, which we interpreted to mean that he is always willing to meet with students who have and act on their interest.

Students' specific content knowledge

Overall, professors did not seem to expect that students who want to engage in undergraduate research come with extensive prior content knowledge. Colin indicated that he does not expect students to have specific knowledge of his field because it is something students typically learn at the very end of their degrees. Malia also said that she does not anticipate that student will come with any specific content knowledge. Arthur only expected "some general knowledge of the domain." Mark mentioned that he looks for students who have some knowledge of programming but added that, for projects that do not require programming, he would just need a student to be comfortable with computers and data. Abby indicated that she looks for students with some background in fluid mechanics, or at least some background in engineering, but admitted that it is more of a preference than a requirement. Noah said that he looks for students that have basic chemistry and some basic math. Richard assumes that early career students have some high school physics and that junior and senior level students have "demonstrated competence in the thermal science courses that require mechanical engineering." However, he added that it can be project specific; he once hired a computer science student for a specific project that required coding.

Students' specific skills

Overall, professors appeared to require very few, if any, prior skills for students who want to engage in undergraduate research. Four professors (Malia, Colin, Richard, and Noah) indicated they have no expectations that students who want to join their research teams will come with prior skills. One of these (Richard) said that he does not have any expectations for prior skills from less experienced students since he sees it as more of a training opportunity for early-career students' learning. However, for junior- and senior-level students, he does look for students who have some concrete skills in programs like Solid Works. Arthur admitted that, while prior lab or work experience that has required students to use machine tools, engineering software, or MS Office programs would be beneficial, he does not typically look for specific skills because he expects that students can pick them up during the research experience. He does, however, consider the quality of their writing when selecting students. Abby felt it was important that students have the ability to think analytically and have some sort of computational background. Mark indicated that programming skills and comfort working with computers would be two skills he would look for in a student who wants to join his lab.

Students' prior experiences

All seven professors indicated that they did not look for an extensive amount of prior experience, if any, in an undergraduate who wanted to engage in research with them. We did not articulate a specific type of experience we were looking for when asking this question and instead decided to let the professors interpret the question as they saw fit. Malia, Noah, and Colin noted that any previous experience would be good, but that it was not required. Richard indicated that he would look for a student who was able to demonstrate they had done something outside of the classroom, including working a job (even at a grocery store) or having experience with a "society" (which we interpreted to mean experience with a professional or discipline-based society). He added that he also looks for students who have some experience in an engineering machine shop or those who enjoy fixing bikes or cars. Mark was the only professor who indicated that he explicitly looks for programming experience, but nothing else. Arthur noted that the type of prior experience he looks for depends on his needs. If there was no specific skill set he was looking for, he would not be looking for any specific prior experiences. However, he also indicated that he would look to see if they have any prior work experience because it would demonstrate they were able to take on the responsibility of another job while being enrolled in classes.

Students' traits related to student demeanor

Professors had a wide range of responses when asked which traits related to a student's demeanor (i.e. traits relating to the student's attitude or personality) they look for in an undergraduate who wants to engage in research with them. All seven mentioned that excitement, enthusiasm, passion, or interest in the work was something they looked for. Four (Colin, Mark, Noah, and Abby) indicated that they look for students who demonstrate a willingness to learn about, and engage in, research work. Two professors indicated that they look for students with positive, proactive attitudes. While Mark indicated that he does not worry about demeanor all that much, he does appreciate a student who is self-motivated, driven and independent, but is also confident enough to ask for help when it is needed. Noah added that he looks for a student who is respectful of him and his graduate students. Abby indicated that she looks for a student who is motivated, but that any other personality type was acceptable; she reflected on working with both students who were more reserved and others who were more talkative. Richard, on the other hand, indicated that he looks for students who are more outgoing. Finally, Arthur admitted to paying closer attention to a student's demeanor than some of the other criteria categories. He spoke about paying close attention to a student's level of engagement when deciding whether to mentor a student.

Students' specific attributes

Professors had various responses when asked which student attributes (i.e. the habits or practices that a student demonstrates) that they look for in an undergraduate who wants to engage in research with them. Three professors (Arthur, Malia, Colin) highlighted the ability to effectively communicate as an important criterion. For example, Colin felt it is important that a student is able to communicate any safety issues they noticed and to communicate what they were comfortable doing. Three professors (Abby, Arthur, Richard) indicated that an ability to work on a team was a key consideration. However, Abby also felt that an ability to work independently was important. Mark added that he looks for a student who takes ownership of their work.

Malia felt it was important that a student is organized, pays attention to detail, and follows instructions. Noah noted that he looks for a student who is responsible (e.g. shows up when they are supposed to, takes meticulous notes, and is attentive in the lab). Richard indicated that he looks for a student who demonstrates initiative and is able to articulate why they want to engage in the research. Finally, Abby noted that she looks for a student who can be an ethical researcher; i.e., someone who does quality, honest work and does not try to get results without putting in the effort. She also indicated that she appreciates a student who is hard working and is not scared to make mistakes and own up to them.

Other selection criteria

Professors mentioned several other criteria that they consider when selecting students that did not fit into the categories outlined above. Four professors (Richard, Abby, Arthur, Malia) spoke about the extent to which they consider academic performance as a criterion when selecting an undergraduate researcher. While Richard admitted to generally having a sense for how students are performing in his classes, he said that he does not use GPA as a great measure for a successful undergraduate researcher. In his words, “I mean, honestly, some of my best undergrad students don't have very good GPAs.” However, he added that he typically hires students from his own major and does look at their grades in relevant courses. Malia and Abby both indicated that they do not worry about a student’s GPA unless the student is applying for an undergraduate research experience as part of an organized program that requires information about academic performance in the application process. Finally, Arthur indicated that he sometimes looks at a student's level of success in their coursework but does not pay too much attention to it since he recognizes many students are early in their college careers.

Noah indicated that he typically looks to see if students are committing to completing an undergraduate thesis since he has had good luck working with this demographic. He also considers his own capacity to take on a new student, whether the student comes with guaranteed funding, as well as the student's major (he prefers students in his own major but it is not a requirement), career goals, and reasons for wanting to participate, and. He said:

> I don't like it when students don't have funding, because I worry about the exploitation factor. If they come in completely unfunded, and they just want to volunteer, then I try to keep their hours to a minimum. I'm like, okay, six hours a week, and then we'll see if we can turn this into something else that's more appropriate.

Colin noted that he does not have extensive criteria since he recognizes that none of us have experience starting out. However, he did admit that he prefers that students enter the lab during their sophomore year because they have already spent a full year acclimating to life at the university but still have a few years to engage with the research. Malia also admitted to preferring early-career students (in her case, freshmen) because they potentially have several years to engage in research. Mark shared that he did not have too many criteria because working with an undergraduate is relatively low-stakes. He said:

> I'm not too picky, in part because usually the undergraduate research projects are low urgency, there's not a lot riding on them… I try to find kind of individual projects for the students to work on, that, if it doesn't work out, it's not that big of a deal.

Richard indicated that he looks to make sure the student has a grasp of what the research group is doing and makes sure to ask whether the student expects to be paid or not. He recognized that when students are not paid, the research experience may not be high on their list of priorities. Arthur added that he looks to see whether a student’s discipline is relevant to the research project and considers the students responsiveness to email. He worries that a lack of responsiveness to email could be an indicator of how many other distractions the student is dealing with.

Finally, Abby mentioned that she typically asks students to volunteer in the lab for one term as a test to see how the student is adjusting. She said:

> Also, I ask them to do one term volunteer in the lab and it seems like it works… During that one term they could just not come much or not interested or are not on time or whatever and then it could also be the other way and they

could be very interested and I get feedback from the group. If it works out, if I can see they are working, then they get involved in projects.

Students not typically selected

Three professors (Mark, Noah, Malia) indicated that they have turned students away when they no longer have capacity to mentor additional students. Richard and Mark both mentioned that they would turn down students who were unable to articulate why they were interested in their particular field of research. In some cases, Mark noticed this when students asked him for a research experience very late in their undergraduate degree and seemed desperate to enhance their CV before graduating. He added that he would not select a student if he and the student both lacked ideas for a research project. Noah indicated that he would turn down a student if he did not have any project ideas or if, upon meeting with the student, he realized that the student would be a better fit for a different professor's research group based on their interests.

Noah and Malia indicated that they might turn students down who did not demonstrate professionalism. Malia had once decided not to continue working with a few male students who were not on time, did not show up when asked, and were making messes when completing basic tasks. Noah added that he would not work with students who were not organized, were disrespectful, or had an attitude. Two professors (Noah and Richard) indicated that they would not work with a student if they had prior knowledge that the student's performance in a class or behavior was unfavorable. Richard noted that he would hesitate to work with a student who barely passed one of his classes and did not submit homework assignments since this could translate into unprofessional behavior in the lab. Noah also mentioned that he would hesitate to work with a student if he heard from other faculty, teaching assistants, or graduate students that the student was difficult to work with. Noah added that he would not select a student if there was a clear personality conflict, which we interpreted to mean that the student would not work well with the professor or research group. Finally, Colin indicated that he has never turned a student away but that it was possible he has scared a few students off after explaining the level of commitment he expects from his undergraduate researchers. This question was not asked of Abby or Arthur.

Do faculty make their criteria explicitly known?

Faculty had a range of responses when asked whether they make their criteria for selecting undergraduate researchers explicitly known to undergraduates interested in engaging in research with them. Most faculty indicated they do not make criteria explicitly known but do communicate any important considerations to students before they begin as researchers. For example, Colin said that he does not make his criteria explicitly known but that he does communicate certain ground rules for those who work in the lab before a student actually engages in research (even though these would not typically show up in any advertisement for a research position). Similarly, Richard did not think he made his criteria consistently explicit since he does not have a list of preferred and required qualifications. However, he mentioned that he would meet with a student who had expressed interest in working with him and explain what projects were ongoing in the lab and outline his general expectations (e.g. to attend meetings, to be on time, to work closely with the team). Noah also indicated that he does not make his criteria explicit but that interested students would usually come talk to him and they would “work it out.” Abby indicated that she does not make her criteria explicitly known unless a student is applying as part of a formal program, which would have its own requirements. Abby said, “my goal is to provide as low an entry point for students to discover something that they might get passionate about.”

For Mark, the criteria he used to select undergraduate researchers depended on whether the student was applying for a specific job opening or whether the student demonstrated interest in engaging in research without applying for a specific position. If a student came in with interest but was not applying to an existing opening, he would craft an undergraduate research experience around the student’s skills. In those cases, he would not have prior expectations or criteria to make explicit to the student. On the other hand, if he had a specific job opening available and he needed a student to be comfortable with a specific program, like Python, he would make that explicit when communicating with an interested student. Arthur also indicated that he does not typically make criteria explicit but if he has a specific position he is hiring someone for, he would communicate the technical aspects of the position. However, he clarified that it would depend on the project. Malia said that when students ask what to expect, she would explicitly tell them that they do not need to worry about having specific skills but that they need to be organized, interested, excited, and able to follow protocol.

Things faculty look for that are not part of explicit criteria

Four professors indicated they have biases related to supporting students from historically underrepresented groups. Colin, for example, admitted to having a bias to support those with a specific need, typically a financial need, over a student who has not demonstrated a need. Noah also talked about how he tries to be intentional about maintaining human diversity within the lab. While he does not treat this as a requirement, he admitted that it is something he is aware of. He adds:

> I also have a soft spot for students from small communities, okay? Rural communities, that was the kind of the community I grew up in. Okay, they might have not had the same high school experiences as others, as well.

Malia also admitted to having a personal bias to accept students from groups historically underrepresented in engineering over white, male students. Richard noted that he often has access to funds for underrepresented students so he will sometimes look for students who qualify for those funds, even though he does not make it an explicit part of his criteria.

One professor indicated that something he looks for outside of his explicit criteria is a student who can who can understand what he is talking about and can follow up, ask questions, and “take it to the next level.” Another professor mentioned that, while she would not be explicit about it, she would be looking to make sure a student was respectful, did not have an attitude problem, and appeared to be easy to communicate with. Finally, Arthur indicated that he would be looking at the student's level of interest in the general topic or research area. He said:

> What I would really like to do is see, for them to continue on and to get interested in something else, beyond whatever that first project is and to participate in other projects, in other ways, and just be interested in the domain area.

RQ3. What Barriers do Students from Historically Underrepresented Groups in Engineering Face when Trying to Secure Undergraduate Research Positions?

Students' own challenges to participation

We now turn to results from student interviews. Whether they had been successful or not, students interviewed in this study who had tried to secure undergraduate research positions noted challenges to their participation. At one point, James tried to secure an undergraduate research position but was unsuccessful because the professor already had too many students involved. James felt that professors should use a more impartial system of advertising open positions for undergraduate research instead of just creating positions for students who reach out. However, he also indicated that by not advertising positions, professors attract students who demonstrate initiative and are willing to commit to the experience. James indicated that he did not experience any challenges related to obtaining his first research position through the STEM Diversity Program. He said, "Well, with my first experience, which was with [the STEM Diversity Program], that was more me signing up for the program and the rest kinda taken care of it. What I really had to do was find a professor who's conducting research that interests me and then contact that professor."

Both Tony and Emily indicated that a lack of time has been one main challenge to their participation in undergraduate research. Although she expressed interest in doing research again, Emily had not reached out to professors since her last undergraduate research experience ended because she worried that she could not commit enough time to make an appropriate contribution because of her heavy course load. Emily also indicated that she found out late about a list or advertisement of paid research positions at the university, which served as another challenge to her continued participation in research.

Cindy faced challenges trying to secure an undergraduate research experience within engineering, which is why she was doing research with a professor in a STEM field outside of engineering at the time of the interview. She attributed these challenges to the fact that undergraduate research positions are highly competitive in engineering and that "if you're not one of the top tiers or that kind of thing, or have past research and like high school experience, that kind of thing, that it's harder for you to even get a foot in the door." She was also dealing with a family health issue when she applied for a formal undergraduate research program, which she felt took her focus away from making her application as competitive as it could have been. However, she indicated that even though she did not have a lot of connections or research experience when entering college, she applied for a number of programs and reached out to multiple professors. While many of these opportunities did not work out, ultimately, her persistence and determination enabled her to access an undergraduate research experience.

Several times throughout the interview, Cindy mentioned that students who participate in a research program for high school students from historically underrepresented groups have a better chance of securing undergraduate research because they make early connections with professors on campus. She expressed disappointment that she was not able to participate in this program before entering the university.

Karina noted a variety of challenges to participating in undergraduate research, including not fulfilling the curricular requirements to do research, not being aware of all the research opportunities available, experiencing difficultly balancing employment and academics, and being at a disadvantage because she had to retake a couple of courses, which she felt could impact one’s ability to engage in research. She expressed some frustration with this and made the point that grades do not always reflect a student’s capacity for excellence in research:

> I don't always think that your grades reflect how hard working or how capable you are of doing research. And I know that's like a problem for a lot of students, is like we may not have like the correct GPA, but I feel like everybody has a story and maybe yeah, some students just aren't applying themselves, but I feel like even if you apply yourself and you're not doing that

> great, I don't think like the paper definition of you reflects how capable you are of doing research.

Karina also shared some personal challenges she faced before attending the university that made it difficult for her to apply for college and secure internships, including the fact that she was unable to participate in extracurricular experiences in high school because of obligations at home. In her own words:

> I don't have that many [extracurricular experiences] just because like my home life in high school wasn't like always like the most flexible for me to like join clubs or like, or I especially I think for a lot of students moneywise like getting internships and um, even like doing research. I know sometimes students get paid and sometimes they don't, but some students can't afford to like choose between having like a job that is paying them and doing research even though that would be good for them… for me, it was like I could go to school and then I had to like go home and help take care of my niece and nephews and um, just a lot of other personal family stuff that just didn't allow for me to like go out and basically be a normal teenager. And now I like, I didn't realize it as much then in high school, but now when I look back on it, when they ask about like things that you've done, I'm like, wow, I really, I really haven't done much outside of like going to school and then like taking care of kids. That's all I really know.

Karina also indicated that she has struggled with getting the letters of recommendation that are often required in her department in order to get research experience. She said:

> I know one problem that I personally have and then I know of a few other students is like creating relationships with professors because a lot of times, um, whether it's like an internship or research, sometimes they ask for like recommendations from a professional faculty in your department. So like an engineering or a math or science faculty member. And that's kind of hard because like you may have done well in those classes but you didn't always like meet, talk to your professor. So I know that's like one barrier that I at least, or that's one setback that I have.

Michael, who had never participated in undergraduate research, indicated that his computer science program does not adequately inform students about research programs that are available. Michael's rationale for not trying to participate in research was that he "ha[sn't] really been reached out to yet." He referred to a student he knew who received an email from a professor encouraging her to participate in a research program but he thought the size of his department was too big to facilitate those types of connections.

Ethan did not experience any challenges related to getting involved in undergraduate research because he started through the STEM Diversity Program and continued to work with the same research team even after the program ended. With the help of facilitated access to undergraduate research through the STEM Diversity Program, Ethan said, "I've never really gone into looking for [undergraduate research], and I've never asked about it." He felt like he was in an advantaged position by qualifying for the program upon entering the university.

Does everyone in engineering have equal access to undergraduate research?

Emily, Michael, James and Cindy all indicated that it seemed like there was equal access to undergraduate research but each student provided caveats that made them think equal access was not actually the case. Emily felt that, while there were plenty of opportunities for undergraduate research, some students may be less likely to access these experiences because professors do not often advertise their research. She added that some students may not have equal access because approaching a professor can be intimidating, students may not know how to get involved, and a student may not feel like they have the credentials to participate. Michael indicated there was equal access at first but then noted that students who perform better in their classes and build stronger resumes would be selected for undergraduate research over other students. James pointed out that, while marketing strategies made it seem like there was equal access, some students come in with more connections to professors than others. According to Cindy, there is equal access to undergraduate research but students have to put in the work to earn it. On the other hand, she indicated that students who participated in a research program for high school students from historically underrepresented groups have a better chance of securing undergraduate research because they make early connections with professors on campus. She also made the point that students with more financial security tend to have easier access to opportunities for undergraduate research. She says:

> Anything you try to make equal, people that have more money, or I've seen with a car, or that kind of thing, that can get themselves to the place, have a better access to it than people that have to walk there, that kind of thing.

Tony, Ethan, Karina had different perspectives. Tony was unable to answer since he had not yet attended the university of this study in person. Karina felt that not all students have equal access to undergraduate research since some students may not know anyone with college experience that could help them navigate the process of engaging in undergraduate research. According to Karina, access to undergraduate research depends on which programs students are associated with and whether students have regular access to a computer and the internet. For example, Karina indicated that she would not have known about internships or undergraduate research opportunities, in general, if she had not been in the TRIO Student Support Services programs [a set of multi-institutional programs that provide support to students from historically underrepresented groups]. She also recognized that students who participated in the STEM Diversity Program were at an advantage because they were guaranteed access to undergraduate research early on in their undergraduate degrees.

Ethan indicated there was equal access to undergraduate research. However, he pointed out that he did not have to struggle to find undergraduate research because he participated in the STEM Diversity Program and he surrounds himself with students who are successful in their classes, have all landed research opportunities through the Multiple Engineering Cooperative Program (MECOP), a competitive internship program, and have not experienced any obvious challenges related to participating in undergraduate research. According to Ethan:

> Everyone can ask. It's not like, you know, there's nothing stopping a student from asking if they can join a lab. The fact that if you're too nervous to ask, that's more on you than it is for it to not be equal access. The access is there, just you yourself are stopping you from doing it.

General barriers for students in engineering

While there may be some overlap of ideas between this section and the previous ones, we choose to keep them separate as they were asked as distinct research questions to participants. Ethan, Michael, and Cindy indicated that competition was a general barrier to accessing undergraduate research for engineering students. That is, they felt that many students are interested in undergraduate research but that there are a lack of available positions. Cindy highlighted that some students are even doing research in high school, which gives them an advantage when they get to college. Karina and Emily both pointed to informational barriers that could prevent engineering students from participating in undergraduate research, i.e. students may not know about opportunities or how to get started. Emily and Tony both indicated that a lack of time due to an intense course load could serve as a general barrier to accessing undergraduate research in engineering. Emily worried that this intense course load would make her unreliable (e.g. during weeks with midterms) and unable to contribute sufficient attention to a research project. Cindy felt that fear of talking to professors (especially for early career students), fear of rejection, and fear of not knowing what to say when interacting with a research team could all serve as barriers to participation. She also pointed to the fact that professors are extremely busy and labs are typically very full, which could also serve as barriers. James felt that a lack of confidence might mean that a student would fail to take initiative and reach out to a professor about engaging in undergraduate research.

Barriers for students of color in engineering

Not all participants were able to identify barriers to accessing undergraduate research that were specific for students of color. Two students, Tony (who had not yet started taking classes on campus) and Ethan (who gained early access to undergraduate research through the STEM Diversity Program), said they did not know. Both Cindy and Michael alluded to the fact that they did not think there were any unique barriers since they felt the university of this study was relatively open to supporting diversity. Cindy felt that increased accountability at the university of this study has helped to reduce biases that faculty may have.

However, several students were able to identify unique barriers for students of color. Emily and James both mentioned that underrepresentation in engineering and a lack of faculty of color meant there were a lack of role models for students. According to Emily, not finding professors that look like you can be intimidating and "really does have an impact on how you feel you can be successful in a class." She said:

> And even through my internship, I hardly saw any women, and so it kind of singles you out. And so that's one way of being a minority, but then on top of that being a person of color and not having many professors to necessarily identify the same way can be discouraging, and so I think it's easier to maybe start that conversation with someone who has a similar background to you, and I don't think that that's a necessity but I think that in many cases in a campus that's so large and not necessarily always has groups of minorities that kind of congregate in a way, it can be difficult to find your place in that sense, but I don't know if there's necessarily ... that it's necessarily harder for students of color, but I think that it's the same type of experience that they generally have of just not necessarily feeling supported or having resources available to them…

James mentioned this lack of role models could translate into a lack of belonging, especially because he feels safer saying what he believes if there are others in the room that look like him. However, James also mentioned that he knows professors who go out of their way to encourage students of color to engage in undergraduate research.

Karina seemed to have an easier time identifying unique barriers to accessing undergraduate research for students of color. She pointed to the fact that some students of color may not be aware of undergraduate research opportunities and may not have a family member who has been to college before to help them navigate opportunities for undergraduate research. Karina also mentioned that time and money likely serve as barriers to accessing undergraduate research for some students of color, including those who might be at the university of this study on a student visa and lack the financial support of family. Finally, she made the point that family dynamics and social upbringing could affect access to undergraduate research from some students of color. She said:

> Most students of color I think, um, tend to have different backgrounds and kind of like with mine, maybe we grew up with different family dynamics or situations that we had growing up that kind of put us behind, I guess in the running against other students who maybe had more opportunities.

When asked to elaborate on what is meant by “different family dynamics”, she explained that some students of color tend to struggle a little more financially, which can affect access to educational opportunities.

Barriers for women in engineering

Ethan and Tony said they did not know whether women in engineering faced any unique barriers to accessing undergraduate research and attributed this lack of knowing to the fact that they did not identify as female. Tony said:

> I've been so like blinders, I haven't kind of been paying attention to other stuff plus I'm a guy and I'm a mechanic. Um, I'm probably not the best person to ask about this kind of stuff. I mean, really, I, I would hope not, but I mean, I, I know it happens. So, I hope not.

Tony did recognize, however, that underrepresentation could lead to some challenges for women in engineering. Michael did not think women faced any unique barriers, although he felt that underrepresentation could lead to increased competition.

Emily and James both indicated that a lack of role models could serve as a barrier for women. Emily felt that it was discouraging and intimidating to be continuously taught by men and not see female faculty in the field. James pointed out that this could affect a student's sense of belonging in engineering, which might be especially hard for those who lack confidence. Karina pointed to discrimination against women as a barrier to accessing undergraduate research in engineering. She illustrated this point with an anecdote about a friend:

> I do know of one friend in particular who applied to do research with a professor who openly stated that male, a male like opponent or another male student would get it, um, had they been considered like had they been equals and they had the same grades and all that, that the male would be preferred because they think that they could handle the workload more or something like that and so I do feel like there's some discrimination against what females can do, especially in engineering research.

On the other hand, Cindy felt that there were fewer barriers for women now because of an increase in faculty role models, at least in her engineering discipline. She also felt that a campus-based student club for women in engineering helped to reduce feelings of competition and by encouraging students to support one another.

Barriers for LGBTQ+ students in engineering

Three students (Cindy, Michael, and Karina) felt that faculty bias and discrimination could potentially serve as a barrier to accessing undergraduate research for students who identify as LGBTQ+. Karina, for example, indicated that some faculty in her department had biases against certain students, which would make it difficult for a student identifying as LGBTQ+ to access undergraduate research if there were limited opportunities available. Tony felt that there were probably barriers but hoped that they were becoming less salient in engineering. Emily indicated that having few role models and feeling intimidated by faculty who could not relate to them could serve as barriers. She also felt that students identifying as LGBTQ+ might not feel comfortable or confident approaching a professor because of existing feelings of isolation and the lack of a support system. James and Ethan did not know whether there were barriers to accessing undergraduate research for students who identify as LGBTQ+.

Barriers for first-generation college students in engineering

All seven students indicated that there were unique barriers to accessing undergraduate research for first-generation college students. Emily, Michael, Ethan, Karina, and Cindy all felt there were barriers because first generation college students may not have family members who can help them navigate college, including how to talk to professors or learn about undergraduate research programs. Ethan and Cindy both pointed to a lack of family connections and family-supported networking as potential barriers to accessing undergraduate research for first generation college students. Emily added that first-generation college students may not be aware of the value of undergraduate research experiences. She also indicated that families of first-generation college students may not be able to engage in important conversations about undergraduate research opportunities at home, which could discourage participation:

> I think just not having someone who can explain these things, or not being able to even engage in conversation. So, I don't know if ... I mean, depending on the student, but if they go home, it might not be a conversation that their parents ask them about or that they can have with their parents, because it's just ... I know in my case, my parents migrated to this country and so we don't really talk about college, or they just don't really know the questions to ask, and so I think it might be something that the student wants to share with their parents, but it doesn't come up, and so there maybe it's just ... it's not necessarily a priority to engage in it. It's something that they do but can't

> really reflect on with other people, which I think takes away from that experience a little bit.

Karina added that on top of having to navigate higher education on their own, many first-generation college students attend low-income K-12 schools which could limit their access to educational resources and programs that would give them an advantage when attending college and seeking out undergraduate research opportunities. Karina also made the point that some people make assumptions about first-generation college students because their families did not attend college, which could affect access to undergraduate research. She said:

> Well, I'm a first-generation student and for me it's because like, well my mom was here illegally, but then my mom passed away when I was younger and then I didn't really have like a father growing up. So I feel like my parental figures, I didn't have anything to go off of and I don't have, I didn't like have any kind of like support, but I know a lot of my friends whose parents are here illegally, like they run into a lot of issues like even applying for school or even if they're here legally, it just for some reason when people find out that your family or like you're a first generation student, um, I feel like there's some discrimination against you as a person and your ability to work in certain research…They feel like maybe you just don't have the skills that other students would have like coming from a family of alumni from like Harvard or something like that. Like you're just not as dedicated or like I feel like your

family upbringing carries a lot into your, like how you develop your skills and the experiences that you have.

Tony indicated that students with parents who do not have a background in STEM might have a more difficult time with their coursework, which could affect their access to undergraduate research opportunities. James indicated that, similar to students from other underrepresented groups, first generation college students may experience a lack of role models who are professors or who are conducting research, which could prevent them from seeking out undergraduate research opportunities.

Barriers for engineering students from low socioeconomic status backgrounds

Tony, Emily, James, and Cindy indicated that students from low socioeconomic status backgrounds face barriers to participating in undergraduate research because many of these students have to work while in college to pay for school. Cindy made the point that many students do not get paid when they start engaging in undergraduate research in engineering labs. Tony felt this pressure since he has worked throughout college and pointed to the fact that he does not have time for extracurricular activities outside of courses and employment. Tony has not participated in undergraduate research yet and had concerns that 1) undergraduate research opportunities will not pay as much as other jobs and 2) students are limited to working 20 hours per week at the university of this study, which would not be enough hours for him. James has not sought out research opportunities recently because he has had to work to pay for school and cannot afford to volunteer time in a research lab. According to Emily, students from low socioeconomic status backgrounds may be more financially motivated to get through college and find a job than socially motivated, which could prevent them from seeking out opportunities like undergraduate research outside of the classroom. Emily noted that having a college experience that is driven primarily by motivation to finish one's degree and find employment after college can be isolating for some students.

Cindy indicated that it may be more difficult for students from low socioeconomic status backgrounds to be competitive for scholarships if coming from a low-income community meant that a student attended an underfunded high school. She went on to say that attending underfunded schools could mean a lack of access to Advanced Placement courses that could potentially replace college coursework, save students money, and make students more competitive when applying for undergraduate research opportunities. Instead, these students would have to take this coursework in college and may need to work to afford the cost of this tuition and textbooks.

Ethan made the point that students from low socioeconomic status backgrounds may experience challenges accessing undergraduate research that stem from a lack of access to things that some more financially secure students may take advantage of, like access to a cell phone and WiFi at home, and being able to live and park near campus. He explains:

> A lot of people would be just, "Well, I'm just gonna email from home. I've got WiFi, I've got a cellphone, I've got whatever." And lower income families would be like, "Well, I've gotta go all the way to the library and figure out how I'm gonna get a computer. Borrow one or something."… And again, it could also be the fact that low-income students are probably getting housing in places that are more affordable, which are not gonna be as close to campus as everybody else is. It could be that sense of like having access to being so close to office hours and not having to worry about commute times and not having to worry about getting on the bus at a certain hour or whatever. It's just that sense of like, "Yeah, I could just pop into the lab, or I could just pop in and look around at like flyers, and just wander around. Whatever, go to club meetings, whatever I want instead of having to worry about how am I'm gonna get there and back.

Ethan went on to explain that these barriers could mean a student is less connected to what is happening on campus, including resources that may lead to undergraduate research opportunities. Finally, Michael indicated that having to purchase one's own research supplies may serve as a barrier to accessing undergraduate research for students from low socioeconomic status backgrounds. Karina was not asked this question.

Barriers for engineering students who have to work while in school

All seven student participants indicated that a lack of time would serve as a barrier to accessing undergraduate research for engineering students who work while in school. The students emphasized the difficulty associated with participating in undergraduate research when it is already difficult to balance non-research employment with schoolwork. Karina, for example, knew "a couple people who had to stop doing research because they needed more hours at like their work and you know, they were just volunteers and not really getting paid for it." More specifically, Emily, Michael, and Ethan indicated that inflexibility related to one's job could serve as a barrier to participation in undergraduate research. That is, a student may feel like a professor cannot depend on them because their work schedule is so complex or they are unable to work in the research lab on days when the research team needs them.

RQ4. Which Selection Processes and Criteria do Students Think Professors use When Selecting Undergraduate Researchers to Join Their Teams?

How professors recruit

Tony, Michael, Ethan, Cindy, Emily, Karina (six of seven participants) indicated that when a professor is looking for an undergraduate student to engage in research with, the professor would typically recruit a student through courses. Tony, who was only beginning to take his first class online at the university of this study when the interview took place, remembered that his professor invited students to talk to him about undergraduate research if they were interested in his work. Michael felt that a professor would look for students who were performing well in higher level classes whereas Cindy felt that professors might recruit students from their lower-level courses. Ethan also indicated that a professor would look for someone who stood out in their class since it would serve as an indicator of interest in the subject. Ethan witnessed this during his first undergraduate research experience. According to Ethan, “the professor definitely looked up the grade that that student got in his class and then made a decision based off that grade as to whether or not he would get into the lab.”

Karina indicated that professors would recruit students who were performing well in their classes and went out of the way to make personal connections with the professors. She recalled an example of this from a fellow student:

> That's how he got his research was that he was going to office hours a lot and kind of like annoying his professor. And then eventually he, uh, asked his professor to work on his research and his professor said yes. At first, he wasn't hiring anyone ‘cause we were, I think sophomores, and he didn't want anyone under a junior. But then since he knew him, he was like, okay, you know, like I can make the exception.

Emily made the point that professors might end up recruiting students (intentionally or unintentionally) by giving talks in other classes about their research. Cindy indicated that professors typically recruit students for undergraduate research through organized programs that provide funding, like the Undergraduate Research Scholars Program. Cindy and Karina also noted that professors might initiate a job posting for an undergraduate researcher and recruit through this more formal process.

James noted that there were unspoken rules about how professors recruit students for undergraduate research. According to James, “they're not openly advertising opportunities, but they're waiting for a great student to come by and offer it.” While this did not seem fair to James, he seemed to understand that it ensured the student was truly interested in the work and was willing to create opportunities for themselves, which would be impressive to a professor.

How students let professors know they are interested

All student participants indicated that students typically let professors know they are interested in engaging in undergraduate research with them by connecting with them, most commonly over email or in person. Emily felt that reaching out via email or in person were both common but that meeting a professor in person had advantages because it allowed the professor to associate a face with a name and provided an opportunity for the professor to get to know the student better. In her experience, it worked well to introduce herself to a professor in person and then quickly follow-up with an email. She spoke to the importance of communicating what you can bring to the experience but also being honest with the professor about one’s experiences, qualifications, and primary focus on coursework.

Both Emily and James highlighted the importance of expressing sincere interest in a professor’s research before explicitly asking for an undergraduate research position. James felt this was important because a “professor wants to know that whoever's working in their lab is interested, passionate about what they're doing. Not just in it to throw it on their resume or things like that.” Michael added that a student might even attach a resume to their initial email to a professor. Ethan made the point that initiating an undergraduate research partnership was more student-driven than faculty-driven since faculty likely know students will come to them with interest. Karina indicated that a student might simply apply to an open undergraduate research student job posting. According to Cindy, email was best because reaching out to a professor in person could be intimidating, especially for younger students who have not yet taken classes with the professors they want to engage in undergraduate research with. She explained that email allows one to proofread a message before sending it and that it is less embarrassing if the professor does not reply. Cindy did indicate that students who participated in a research program for high school students, may already know professors on campus and, for that reason, may reach out to them in person. Tony felt that a student would reach out to a professor in person but admits that he has not been exposed to a university setting yet so he was not confident about this process.

How professors prefer students let them know they are interested

Student participants were split on whether professors would prefer students let them know they are interested in undergraduate research over email or in person. Ethan felt that email was preferred because it allowed for documentation of the interaction and because professors might forget an in-person interaction that occurred after a busy lecture. Emily spoke to the importance of emailing a professor as soon as possible after meeting them in person so that your initial conversation and interest was fresh in the professor’s mind when you made that second contact over email.

Karina indicated that email would be preferred so the professor could respond on their own time.

James, on the other hand, indicated that professors would prefer that students reach out in person because it would demonstrate the student had taken the initiative to look up a professor's schedule and find times when they are available. According to James, a professor would prefer that you "just find them in their free time when they're not doing anything." Cindy indicated that professors prefer students let them know they are interested during in-person events like faculty mixers, or through organized programs, like the Undergraduate Research Scholars Program, since these are things the professors have already committed to participating in. Michael felt that faculty preference for email compared to in-person contact depended on the professor and that some may prefer email, while others may prefer that you initiate a conversation with them in person (e.g. during office hours).

Tony focused more on the content that professors prefer students include when they first reach out. He indicated that professors would appreciate it if students were able to demonstrate their competency in that initial correspondence, for example by providing a resume and/or transcript. Cindy also highlighted that professors would prefer that students demonstrate sincere interest in their research during these initial meetings. According to Cindy, failing to show sincere interest could put a student at a disadvantage, especially because faculty receive so many emails.

Students' specific content knowledge

When asked what specific content knowledge, if any, they thought professors would look for in a student who wanted to engage in research with them, Tony, Emily, Ethan, and Cindy all indicated that professors might be looking for students with content knowledge from specific courses they have taken in order to ensure they had a certain baseline knowledge before beginning an undergraduate research experience. Cindy was less certain that professors would be looking for any specific content knowledge at all, but indicated that, in engineering, some professors may be looking for students who had advanced further in their undergraduate degrees and have taken the transport classes. However, she also indicated that some professors are willing to take less experienced students if they demonstrate drive and a willingness to learn. Tony and Emily both felt that the specific content knowledge professors were looking for depended on the nature of the research project.

Both Michael and Karina indicated that professors might be looking for a student with foundational knowledge in the sciences. For example, Michael felt a professor would look for a student who has some knowledge of the basic subject they are doing research on, e.g. basic knowledge of math or chemistry, if those were subjects related to the research. Karina indicated a professor might look for a student with foundational knowledge in the sciences (e.g. chemistry, physics, biology) or familiarity with computers. She added that having computer skills was actually a requirement for students in her program before they could conduct undergraduate research with a professor. Finally, Ethan added that a professor might ask if the student had any experience related to the research being conducted as a way to gauge what content knowledge the student would bring to the experience.

Students' specific skills

When asked what specific skills, if any, they thought professors would look for in a student who wanted to engage in research with them, Tony and Ethan both felt the skills would be specific to the type of research being conducted. However, Tony added that some professors might look for programming skills. Michael and Ethan did not focus on the specific skills professors would be looking for so much as the importance of being able to quickly and creatively transfer skills from one subject area to another. For Ethan, there were specific problem-solving skills related to being a mechanic that he was able to use in unexpected ways. Cindy added that professors might look to see whether a student has skills that would transfer over from a previous research experience, e.g. skills associated with participating in a lab safety training. James added that older students would benefit from having skills related to presenting their work.

Students' prior experiences

When asked what prior experiences, if any, they thought professors would look for in a student who wanted to engage in research with them, Tony mentioned that professors might look for "somebody who has been an employee for a long time" and who had experience in a work environment. However, he did not articulate which specific type of work experience would be beneficial. Tony added that professors might look for students with prior research experience. Cindy indicated that professors would look for prior experiences (e.g. research experience or participation in student organizations) that would demonstrate the student had gained skills in communication and time management. Karina also pointed to the importance of having prior laboratory experience (which she felt could include course-based undergraduate research experience), since it was a requirement if students wanted to engage in research in her major. Michael indicated that professors might look for students with lab experience or experience with computers.

Emily indicated that a professor looking for an older student might look for internship experience because it would mean they have site experience and know some of the important disciplinary terminology. She also felt it would demonstrate to the professor that the student was hirable, which would distinguish them from other students. However, she added the caveat that a professor may also prefer a student without research experience who is willing to learn so the professor can, in her words:

> Kind of mold the student into how they see fit and explain their research pretty much with their own methodology, as opposed to a student who has learned something by one professor and then begins working with a second professor who has to kind of alter their scientific processing.

Michael and Cindy both connected the importance of prior research experience to experience with lab safety. For example, Michael felt that experience with computers and experience in a lab would be important because the student would have a sense for lab etiquette and safety protocol. Cindy also mentioned that having prior experience with safety training would make a student more desirable. One student, Ethan, indicated that professors would look for experience that students have had in previous classes so they can ensure students have a certain foundational knowledge. James indicated that professors would look for different prior experiences depending on how far the student had advanced in their degree. He explained that, when he was a freshman, professors expected him to demonstrate interest but did not expect him to have extensive experience. However, if he were to seek out an undergraduate research opportunity now, he felt that professors would expect him to be interested in the work in addition to demonstrating "professional traits." Finally, Emily mentioned that speaking additional languages or having travel experience could even serve to set a student apart from others who were interested in undergraduate research.

Students' traits related to student demeanor

When asked about the specific traits related to a student's demeanor (i.e. traits relating to the student's attitude or personality), if any, that they think a professor would look for in an undergraduate who wants to engage in research with them, Emily, Tony, James, and Cindy all indicated that professors would look for a student who demonstrated sincere interest in the work. More specifically, Emily felt it would be important that the professor gets a sense for the type of engineering a student is interested in pursuing in order to ensure the student and professor's research interests align. James added that interest was one of the more important traits professors look for when a student is still inexperienced.

Two students indicated that being outgoing was important. Cindy felt that being outgoing was preferred because these students would be easier to talk with and would be more likely to reach out to a professor in the first place. She indicated that, for those who are more introverted, demonstrating a passion for the work could overcome any potential challenges related to being more reserved. Ethan felt it was important that the student was outgoing and talkative because it would help to create a more collaborative research environment and assure the student's mentor that the student would speak up if they needed help. However, Ethan also went on to say that he has seen students with different personalities doing research so he would not necessarily say professors are after a certain type.

Tony and Michael mentioned that professors might look for a student with patience since research does not always go according to plan. Michael added that having drive and determination would be important if the work became more challenging than expected. Emily added that a professor would look for a student who was willing to learn, i.e. someone who ask questions and is able to provide feedback. She felt it was important that a student could:

> Go outside on their own to get some background knowledge on it and to kind of get caught up to where the professor is so they don't ask basic questions, but they can start asking questions that build off of basic concepts and a little bit more sophisticated questions.

Finally, Karina felt professors might look for someone who would personally connect with and enjoy the research instead of someone who treated it like a job. Tony felt that maturity and excitement about a project would be important, although he recognized that each professor is different and each may be looking for students with different personalities. Karina felt professors would look for a student who was open minded and open to learning new things.

Students' specific attributes

Students had a range of responses when asked which student attributes (i.e. the habits or practices that a student demonstrates) they think professors look for in an undergraduate who wants to engage in research with them. Six of seven student participants (Ethan, Tony, Emily, Michael, James, Karina) indicated that professors would look for a student who was able to work well and get along with others. According to Emily, this also meant professors were looking for someone who was willing to get to know the professor on a personal level since professors like to know they are helping to guide students along their career path. Karina felt that professors would look for someone who was personable but also professional when they needed to be. Tony elaborated that professors would look for a student they felt they could get along with, which he felt may be more important than a student's previous coursework and grades.

Emily and Cindy indicated that a professor would look for a student who demonstrated professionalism. More specifically, James, Emily, Karina, and Cindy all indicated that professors might look for students who were good communicators. Karina, Michael, and Tony all felt that being a hard worker was an important attribute. Michael indicated that a professor would look for a student who was a quick learner and who demonstrated leadership, responsibility, and accountability. Ethan added that a professor would look for a student who could meet deadlines and was professional, flexible, and available when needed. Emily indicated that it would be important for a student to show initiative and to be punctual and mature. She also mentioned that a professor would look for a student who could work independently.

James and Cindy indicated that professors would look for students who were organized. Both students pointed to previous research experiences where skills related to organization and attention to detail were critical since they had to keep track of data over extended periods of time. According to James:

> There had been times when ... like in my research internship where I would obtain a set of data and then come back to it weeks later, that kind of thing. And in those situations, it's really important for me to just know where everything is because I would connect some kind of data that I've obtained here, I would try to connect it with obtained weeks before that.

Cindy described a similar situation:

> Our lab manager hates it when it's disorganized, and it's really hard to find things that you're looking for. We go back years and years on data. I'm working on 2016 data right now, and you have to be really organized to be able to find that data three years later now.

Cindy indicated that a professor would look for a student who was tidy and who was not afraid to try new things even if it meant getting a wrong answer. James added that professors might look for someone who had the ability to think critically. Finally, Ethan explained that he did not think a specific attribute would imply a student was good at something since he knows students who are very unprofessional but are incredibly smart and would probably do very well with undergraduate research. On the other hand, he also knows students who are incredibly “book smart” but are unable to solve complex problems. He said, “that would be my guess as to why they wouldn't look for a particular trait in anything because you don't really know what you'll get.”

Other selection criteria

Students mentioned several other criteria that they thought professors would consider which did not fit into the categories outlined above. Tony, Michael, Ethan, Karina felt that professors would consider a student’s grades and performance in class when selecting a student to join their research teams. According to Karina:

> Yeah, only just because of like the few, um, like research opportunities I read about, they're always saying how like there's a standard GPA and they're just wanting to make sure that like kids are doing well. Like they want to give the advantage to kids who are doing well in their classes.

Tony, Emily and Cindy indicated that professors would look at which courses the student had enrolled in. Cindy thought professors would look at a student's major and Emily felt the professor would consider a student's class standing. Finally, James pointed out that professors would be looking for a student who was "okay with the boring part, the repetitive part of research."

Students not typically selected

When asked to describe the type of undergraduate student they thought professors typically would *not* choose to engage in research with, four students (Emily, Ethan, Karina, Cindy) indicated that professors would not typically select students who were not performing well in their courses or taking their courses seriously, including those who skipped lectures or were not demonstrating a drive to learn. Emily felt that professors would not select someone who did not have a good work ethic or was not reliable, which could become apparent if the student was not performing well or dedicating sufficient attention to a class the professor was teaching. Ethan explained that poor performance in coursework could be seen as a behavior that would carry over into the research environment. Both Tony and Cindy indicated that professors would not typically select students who did not appear to have sincere interest in the research. Cindy elaborated that it could be difficult in some contexts for professors to see whether a student was interested in the work, especially if the student's parents were making them participate or if their written application to a research program was stronger than their in-person performance.

Emily and Michael indicated that professors would not typically select students with certain personality traits. Emily felt that a professor would not select someone who had a personality that clashed with their own. Michael added that professors would not select someone who was “shy or understated,” someone who did not work well with others, someone who was a “loner,” or someone who was lazy or careless. James added that a professor would not select a student who dressed unprofessionally or a student who conducted themselves in an unprofessional manner. Finally, Karina, indicated that professors would not select students who did not have prior research or extracurricular experience.

Discussion

Access to Undergraduate Research May Not Be Equal for All Students

Results from this study indicate that students from historically underrepresented groups in engineering may experience unique barriers to accessing undergraduate research and that access to undergraduate research may not be equal for all students. Even some faculty and students who initially indicated there was *equal* access, or expressed some uncertainty about when asked about this, went on to describe barriers to participation that were unique to students from specific groups historically underrepresented in STEM. We interpreted this to mean that these professors and students were not initially thinking about whether students had equal access to opportunities for undergraduate research (and were quick to assume that they did have equal access) but later considered that equal access was not or may not be the case after being prompted to consider unique barriers for students from a diversity of specific groups. For example, one professor, Arthur, first said that students did have equal access to undergraduate research but then later indicated that first-generation college students and students of color may experience unique barriers to accessing undergraduate research because, respectively, their families may not expect them to participate and they may experience “imposter syndrome” per a lack of role models in research.

Generally speaking, professors and students identified a wide range of unique barriers to accessing undergraduate research for engineering students of color, women, students identifying as LGBTQ+, first-generation college students, students from low socioeconomic status backgrounds, and students who have to work while in school. Many of these barriers, summarized in Table 1, relate to issues associated with a lack of representation (e.g. lack of role models, lack of student cohort), racism and other forms of prejudice (e.g. discrimination, microaggressions), or family and financial pressures (e.g. family being unaware of the value of undergraduate research, unable to afford to volunteer in a research lab). We noted that all barriers highlighted by interview participants for students of color in engineering, specifically, aligned with hypotheses put forth in our systematic review regarding how barriers in the way of success and persistence in postsecondary STEM may manifest as barriers to accessing undergraduate research experiences for students of color.

However, asking students and professors to comment on potential barriers to accessing undergraduate research for students from various historically underrepresented groups revealed significant challenges that we had not originally considered. For example, Ethan made the point that students from low socioeconomic status backgrounds may face barriers when trying to engage in undergraduate research if they do not have a cell phone or internet access at home, or are unable to live and park near campus. Here, Ethan articulates nuanced challenges related to a students' personal-financial lives that can impact access to undergraduate research in unexpected yet significant ways. One professor, Mark, indicated that, even if a student was confident enough to reach out to a professor, he would not select the student if they were unable to articulate ideas for a specific research project and no other project ideas were obvious. This point highlights the fact that a professor's criteria can mean that certain students may be excluded from potentially transformative research experiences, even if they demonstrate enthusiasm and interest. Instead, professors could invite these students to participate in lab meetings and help with ongoing projects while the student explores areas of interest.

We were also surprised to find evidence for barriers to accessing undergraduate research that may present themselves even *before* students entered higher education. Karina, for example, indicated that she was not able to participate in some relevant activities in high school because she had to take care of her niece and nephews, and expressed frustration that this may have made her less competitive for opportunities like undergraduate research in college. Challenges like these serve as reminders that access to undergraduate research may not be equal for all students, and that our institutions must work toward implementing strategies that ensure equitable (as opposed to equal) access for students who experience unique barriers (Pierszalowski et al., 2018).

A Partial Disconnect Exists Between Some Student and Faculty Perceptions of the Importance of Academic Performance When Accessing Opportunities for Research

Faculty and students made many similar claims with respect to unique barriers that students from historically underrepresented groups experience when trying to access opportunities for undergraduate research. For example, both noted that students of color may experience challenges related to a lack of role models in engineering. They also both noted that first-generation college students may not have family members who can help them navigate college experiences, including how to access opportunities for undergraduate research. This overlap is encouraging because it indicates some professors have a fairly good understanding of various challenges some students from historically underrepresented groups may face when trying to access opportunities for undergraduate research. This could mean these faculty are more likely to employ criteria and processes that promote inclusivity. For instance, one professor, Colin, indicated that having to choose between an unpaid undergraduate research experience or a paid job would serve as a unique barrier for students who work while in school. In response to this, he pointed out that he does his best to compensate all of his students and encourages them to work in the lab instead of working in food service, for example, since it is more productive toward their career goals.

We also feel it is important to note one partial disconnect between the selection criteria that faculty use to select undergraduate researchers and students' perceptions of these criteria, which could present a potential barrier to accessing undergraduate research. That is, when asked about the criteria professors use to select undergraduate researchers, several students highlighted the importance of high academic achievement and performance in classes. For example, Tony, Michael, Ethan, Karina all felt that professors would consider a student's grades and performance in class when selecting a student to join their research teams. However, when asked about the criteria they use to select undergraduate researchers, several professors downplayed the importance of academic performance when selecting undergraduate researchers or indicated that academic performance did not matter at all.

We assert that students' perceptions of the importance of academic performance are problematic in that this assumption might preclude students from seeking undergraduate research experiences altogether. Consider, for example, a student who has struggled academically during their first few terms at the university. A loss of confidence associated with poor performance in one's courses, in combination with the perception that faculty will not want to mentor them if they have not maintained top grades, could cause students to refrain from attempting to access opportunities for undergraduate research altogether (i.e. they may feel they are unqualified for undergraduate research experiences or they may feel too intimidated to approach faculty knowing they may ask about the student's academic performance).

Using a CRT lens, we are additionally concerned as we consider that traditional metrics of merit, like grade point average, are significantly influenced by a students' access to educational resources in the K-12 system (Brayboy, Castagno, &

Maughan, 2007), which students have limited control over. According to May and Chubin (2003), “Because [K-12] schools with the highest concentrations of poverty are the ones most likely to educate low-income minority students, these students are denied equal access to learning tools important for high-quality mathematics and science education and subsequent entry into engineering” (p. 31). While this reality does not in any way reflect a student’s academic ability, it is possible that this K-12 opportunity gap translates into academic challenges for students (e.g. a lack of high marks), which could predict access to experiences in higher education. Therefore, CRT has us considering the problematic realities of postsecondary institutions (and formal education systems overall in the U.S.) being built upon the meritocratic assumption that the harder one works, the more likely one is to succeed, an assumption that negates considerations of the role of (under)privilege (Gunier, 2015). Such assumptions fail to recognize the role that systems of power and oppression play in influencing student access to educational opportunities and resources (Perna & Finney, 2014).

Organized Programs for Underrepresented Students are Valuable for Promoting Participation, but Sustainable and Comprehensive Strategies are Needed to Promote Equity in Access

Agencies like the National Science Foundation, the Howard Hughes Medical Institution, and the National Institute of Health have begun to recognize the value of diversifying the STEM workforce and have responded by devoting funds to support the creation of organized undergraduate research programs for students from historically underrepresented groups across the country (Jones, Barlow, & Villarejo, 2010; Russell, Hancock, & McCullough, 2007). The value of organized undergraduate research programs was made clear in the current study by both student and faculty participants. Three of the four students interviewed in this study that had participated in undergraduate research were first introduced to opportunities through organized undergraduate research programs targeting students in their first and second years at the university. Both Ethan and James were offered paid opportunities for undergraduate research as first year students through the STEM Diversity Program, a program specifically designed for students from historically underrepresented groups, and, thus, did not perceive any barriers to participating early on. Cindy identified a research mentor as part of her preparation to apply for a campus-wide undergraduate research program for first- and second-year students, the Undergraduate Research Scholars Program.

We have argued elsewhere that formal undergraduate research programs for students from historically underrepresented groups are important because they typically guarantee funding and provide a more equitable means for student participation (Pierszalowski et al., 2018). Faculty recognized that volunteering to engage in undergraduate research is often reserved for students with financial privilege, making organized undergraduate research programs especially important for those who cannot afford to participate in research without compensation. One professor interviewed in this study, Richard, pointed out that because the university under study has programs specifically targeting students from historically underrepresented groups, “there's more opportunities, more different sort of funding opportunities for underrepresented students.”

While there is clear value in offering programs like these, Ong (2005) argues that despite the allocation of domestic funds toward promoting diversity in STEM, “the national call for recruiting and retaining a diverse scientific body rarely translates into an inviting institutional climate for nontraditional students” (p. 595). In other words, students may still experience race-, gender-, and class-based challenges at their institutions which could impact participation in undergraduate research even though programs exist. In addition, some externally-funded programs only last a few years and are not institutionalized after their grant-funded period, making the benefits of these programs fleeting. With these considerations in mind, we may perceive externally funded programs to represent first order solutions, ones that presents a quick, non-sustainable fix to a more complex problem. We contend that many barriers to accessing undergraduate research (e.g. lack of faculty incentives to mentor undergraduate researchers) call for solutions that are permanently integrated into the structures and processes of the institution. That is, more long-term, institutionalized strategies (as opposed to temporary fixes that are funded externally) are needed if institutions hope to create a sustainable infrastructure for equity and inclusion in undergraduate research (Pierszalowski et al., 2018).

Student Agency Influences Access to Undergraduate Research

We found that several students and faculty indicated that a student’s agency and personality would impact their ability to access opportunities for undergraduate research. For example, one professor (Richard) indicated that he looks for students who are more outgoing and felt that accessing opportunities for undergraduate research may be especially challenging for students who are shy or lack confidence. Two students also highlighted that being outgoing was likely an important criterion for faculty who were selecting undergraduate researchers.

When considering these findings using a lens of CRT, we consider how systemic racism and sexism may affect access to undergraduate research. This emphasis on the importance of having an outgoing personality is problematic in that it disadvantages those who are more reserved, including those who have become more reserved because of negative social experiences. For example, experiencing microaggressions within one's discipline could cause a student to actively avoid additional interactions with faculty and peers, making them seem less outgoing (Solórzano, Ceja, & Yosso, 2000; Yosso, Smith, Ceja, & Solórzano, 2009). One professor that we interviewed, Malia, admitted to personally knowing students who have experienced social exclusion and microaggressions, which she believed could have made them more reserved in terms of personality. Noah also stated that female students experience a lack of self-confidence and were more shy and introverted when compared to men, which could be a result of underrepresentation.

Research participants in this study indicated that many student-faculty partnerships are initiated when students reach out to professors either in courses, during outreach events, or when a student sends an introductory email to a professor. All of these processes require students to demonstrate some degree of agency and confidence in order to initiate contact with a professor. Again, those who are more reserved and do not make this initial contact might be mistaken as disinterested or disengaged, when really, they may simply lack the confidence or do not feel comfortable interacting with a professor. Thus, these recruitment strategies privilege those with high levels of confidence and potentially disadvantage those who have perceived a hostile racial or gender climate on campus and are less inclined to interact with faculty (Savas, 2014). With these consideration in mind, it is important to recognize that race- and gender-based challenges in higher education (e.g. experience with microaggressions, social exclusion, lack of role models) could not only make a student less likely to want to engage in research and less confident when trying to reach out to a professor, but might also make the student less favorable in the eyes of a professor who is looking for someone with a more outgoing personality.

Intersectionality Can Mean a Student Experiences a Complex Set of Barriers to Accessing Undergraduate Research

We chose to ask research participants about barriers for students from a range of underrepresented groups given that students' identities often span multiple demographic categories and due to research that indicates that the interconnectedness of race with class and gender may beget enhanced discrimination (Ong, 2005; Wei, 1996). This became evident when Emily responded to whether she felt students of color in engineering faced any unique barriers when trying to secure undergraduate research positions. She used this as an opportunity to speak to challenges related to the intersectionality of her identities as a woman and person of color in engineering.

That is, she found the lack of female role models, in addition to a lack of faculty role models from underrepresented racial/ethnic groups, both isolating and discouraging.

Karina also highlighted challenges related to her identities as a first-generation college student, a woman in engineering, and as someone who identifies as a "lower income student." She noted that first-generation college students may not have family members who can help them navigate college, including how to talk to professors or learn about undergraduate research programs. She also pointed out there was some discrimination at the university regarding what females can do, especially in engineering research. On top of these challenges, she indicated that as a lower income student, she was expected to care for younger family members during high school, which precluded her from participating in extracurricular activities that may have made her more competitive for research positions in college.

Here, Emily and Karina describe challenges associated with underrepresentation related to multiple identities which they felt could impact one's proclivity to access undergraduate research experiences. Similar challenges related to intersectionality have been noted in other studies. For example, in a study about young women of color in physics, Ong (2005) found that one participant "consistently voiced concern about how her position as both a female and a racial minority created cultural dissonance and led to 'serious' messages that she did not belong" (p. 607). This experience of intersectionality has been described by Wei (1996) as being "greater than the sum of racism and sexism" (p. 771), as challenges related to race and gender become more pronounced as they accumulate.

A Notion of Objectivity Might Impede Access to Undergraduate Research

When asked whether LGBTQ+ students face any unique barriers when trying to access opportunities for undergraduate research, one professor (Abby) felt that the objective nature of research should negate any potential biases that students experience when trying to engage in research. She indicated that research "doesn't care who you are," but is more concerned with ideas and creativity, which could come from anyone. While we interpreted this to mean that faculty may not discriminate based on gender identity or sexual orientation, we are weary of this adherence to objectivity in STEM. Utilizing the lens of CRT, we contend that assumptions regarding objective, normative practices in STEM can marginalize students with underrepresented cultural values, ultimately leading to differential access to educational opportunities.

This idea that STEM research must remain separate from one's identity, or that one's identity(ies) must be hypothetically left at the door before one enters the research lab, could make undergraduates from historically underrepresented groups feel unwelcomed or unaccepted in the research environment (Johnson et al., 2007; Ong et al., 2011). For example, Carlone and Johnson (2007) highlight the experience of a Native American female undergraduate student who enrolled in a class with a required dissection lab. When the lab coordinator, department chair, and dean of the college discovered she had cultural concerns about manipulating dead bodies, she was encouraged to change her major.

Another professor in our study (Mark) indicated that trying to access research labs that are dominated by men could be intimidating to female students. He added that some of his colleagues have relatively large research teams that only consist of male students and researchers, which made him wonder what forces were at play to undermine gender diversity in these groups and prevent female students from being included. We worry that faculty may not consider how assumptions regarding objective, normative practices in STEM may marginalize students, especially those whose identities do not align with the majority. These realities may result in students feeling unwelcomed or isolated, causing them to avoid seeking opportunities for undergraduate research altogether.

Implications

One of the strengths of CRT is its ability to connect theory and practice through critically-informed action to foster positive social change for all students, especially those experiencing forms of oppression (Zamudio et al., 2011). Accordingly, CRT allows us to draw on our findings to put forth implications and recommendations for three stakeholder groups with a focus on the promotion of educational equity and social justice.

For Students

We recommend that students who hope to participate in undergraduate research seek out and participate in organized undergraduate research programs during their undergraduate degrees. Participation in an organized undergraduate research program can open the first door to a research experience, which can lead to additional resources and opportunities, as it did for several students interviewed in this study. We also encourage students to participate in other student support programs offered at their universities, including those that are not explicitly designed to fund participation in undergraduate research but that help students navigate engagement in co-curricular experiences (e.g. the United States Department of Education's TRIO Programs). Utilizing university support structures like this may lead to important opportunities for social capital, especially for those who are first in their families to navigate higher education (Martin, Simmons, & Yu, 2013). That is, program personnel and professional development opportunities within programs (e.g. workshops, peer mentoring) may help students build confidence and can offer students the tools to communicate effectively with potential research mentors, including how to write an introductory email and how to prepare for one's first meeting with a professor.

Professors in this study indicated that student confidence and personability may, in some cases, be more important toward securing an opportunity for undergraduate research than other metrics like academic performance. While this reality has its benefits, as considered above, we are concerned that some students who do not demonstrate these personality traits may be less likely to engage in undergraduate research. We highlighted above the social justice implications that make this problematic (i.e., this recruitment strategy disadvantages students who are more reserved, including those who have become more reserved because of negative social experiences). Nonetheless, having agency and confidence do appear to be important criteria for some faculty and we would be remiss to not make this reality known to students, potentially with the recommendation that students who want to engage in undergraduate research may wish to consider investing in strategies that may promote confidence and skills related to sociability, for example, by serving in student leadership positions or acting as a mentor to younger students. Again, we are cautious in recommending that students from historically underrepresented groups who do not demonstrate these personality traits conform to these standards, especially given our concerns noted above, and per underrepresented students' realities of facing "the burden of responding to standards not traditionally designed for them" (Ong, 2005, p. 598) when participating with STEM contexts. Utilizing CRT we recognize that, ultimately, STEM fields are guided by the cultural practices of those in dominant societal positions who designed them (Ong, Smith, & Ko, 2017). This is why we also call on faculty below to explore unintended biases and barriers that they may promote by relying on specific selection criteria.

For Engineering Faculty

While we heard about various practices on the part of faculty that may in fact broaden representation for students from historically underrepresented groups in engineering undergraduate research experiences, we feel it is important for faculty to think critically about the unintended biases and barriers they may promote by holding fast to certain selection criteria and recruitment strategies. For example, by preferentially selecting students with outgoing personalities, professors exclude those who are more reserved, which could present a social justice issue, as noted above. The same is true for professors who tend to preferentially recruit students who make themselves known to professors in courses or during outreach events. One professor interviewed in this study (Richard), for instance, admitted that because time is limited, he typically allows students who are interested in undergraduate research to initiate contact with him rather than reaching out to students himself. It is important faculty realize that having confidence and being outgoing are not necessarily indicators of who will be most successful in a research experience. Therefore, we recommend that faculty consider the types of students they disadvantage by relying on strategies such as these and employ strategies and/or rely on criteria that may be more inclusive. For example, faculty could make an effort to initiate contact with promising students in their courses who appear to be more reserved and encourage them to participate in undergraduate research. They could also consider more holistic conceptions of merit, including drive and commitment to learning, when selecting students to join their research teams (Pierszalowski et al., 2018).

Our study indicated that while some students felt academic performance was a strong indicator of whether one would secure an undergraduate research position, some faculty actually downplayed the importance of academic performance when selecting undergraduate researchers or indicated that academic performance did not matter at all. We recommend that this disconnect be addressed with better communication between faculty and students (and the administrative programs and offices that serve to connect them). That is, we encourage faculty who are not overly concerned with a student's academic performance, like many of the professors interviewed in this study, to be more explicit about this lack of fixation on grades when selecting undergraduate researchers so that students can move away from the perception that their performance in classes will impact their access to research with professors. Faculty can begin to spread this message when giving talks about their research in courses and outreach events, which many of our research participants indicated using regularly to recruit students.

We also recommend that faculty who feel they are already committed to supporting inclusion and diversity through undergraduate research encourage their colleagues to do the same. Several faculty members interviewed in this study alluded to the fact that barriers may exist for students from historically underrepresented groups but that, if they did exist, these problems only occurred outside of their own research teams. For example, Abby did not think there were any unique barriers for students who identified as LGBTQ+ in engineering but admitted that she could only speak for her own research team. She felt that students of color in engineering may face challenges when accessing undergraduate research if a professor had an implicit bias but she felt this was not a problem for her group. Colin also did not think there were barriers to accessing undergraduate research for women in engineering in *his* research program.

While we applaud these professors for their commitments to inclusion, we recommend that professors like Colin and Abby go one step further and employ peer-based encouragement to talk openly with colleagues in departmental meetings or informal settings (e.g. in the hallway, in the nearby café) about the importance of using undergraduate research as a tool to promote diversity in STEM. Instead of treating barriers to accessing undergraduate research as someone else's problem, we also recommend that professors take it upon themselves to tell success stories of students who have joined their research teams and have accomplished great things even though they may not have had prior experience or an impressive grade point average when they joined the research team. We contend this may encourage other professors to relax the traditional, meritocratic criteria that could exclude those who come from less advantaged positions.

For Administrators

Results from this study indicate that some professors may not use academic performance or prior research experience as strong indicators of a students' success in undergraduate research. Results also indicate that our society's focus on standardized metrics of merit like grade point average could be serving as a barrier for students who are not performing well in courses and perceive themselves to be unqualified for undergraduate research experiences they might actually thrive in. Thus, we recommend that administrators of organized undergraduate research programs consider more holistic conceptions of merit that might serve as better indicators of success in undergraduate research, considering traits like drive, personal interests, and commitment to learning (Pierszalowski et al., 2018). We also recommend that administrators of organized undergraduate research programs make these updated criteria explicit to students and faculty in order to further break down the meritocratic perception that grades are a strong predictor of access to, and success within, undergraduate research experiences.

We recommend that when developing strategies to promote diversity and inclusion in undergraduate research experiences, both undergraduate research program administrators, as well as institutional administrators (e.g. college deans, department heads, provosts) acknowledge the possibility that multiple barriers to accessing these opportunities may exist for the same student with respect to various aspects of their identities. For example, a student who comes from a low socioeconomic status background and has to work while in school might also be a first-generation college student whose family is unable to help them navigate the process of engaging in undergraduate research. This student may also identify as a female student of color and experience a lack of role models in engineering. Here, CRT helps us see that race-based inequities can intersect with, and sometimes amplify, inequities related to other forms of identity, including gender and class (Gillborn, 2015). We encourage administrators to acknowledge this complexity and keep this intersectionality of identities in mind when devising solutions to promote more equitable access to undergraduate research for students from historically underrepresented groups.

Specifically, we encourage administrators to familiarize themselves with the student demographic they are hoping to create strategies for in order to better understand the variety of challenges these students experience when trying to access undergraduate research (e.g. lack of role models, lack of family encouragement, lack of confidence). Administrators should then devise targeted solutions that address barriers to undergraduate research related to various aspects of the students' identities. For example, institutions may decide to create an organized undergraduate research program for students that qualify for the Federal Work Study program in order to ensure lower-income students can get paid to participate in undergraduate research. However, this strategy does not address the fact that some students who qualify for Federal Work Study may also identify as women of color in engineering who have experienced social exclusion in their courses and do not feel comfortable approaching faculty. Thus, in order to be most effective, a program that supports this demographic should also include opportunities for coaching students on strategies for identifying and communicating with potential research mentors.

Lincoln et al. (2011) acknowledge that researchers employing CRT seek to change existing institutional policies and practices that introduce inequity. In this paper, we make the argument that externally-funded organized undergraduate research programs are extremely valuable but that more permanent, institutionalized strategies are required to create a sustainable infrastructure for equity and inclusion in undergraduate research. Thus, we call on institutional administrators to devise strategies to promote inclusion in undergraduate research that are more permanent, ones that will persist even if externally-funded undergraduate research programs for students from historically underrepresented groups disappear. Various strategies for achieving this goal include revising promotion and tenure guidelines so that mentoring undergraduates and supporting diversity is explicitly recognized (Schultheis, Farrell, & Paul, 2011), providing incentives or introducing extrinsic motivators like pressure through annual evaluations to improve mentoring and inclusion strategies (Bouwma-Gearhart, 2012), and devoting resources to the development of additional course-based undergraduate research experiences, which have been recognized as a strategy that promotes more equitable participation in undergraduate research (Bangera & Brownell, 2014; Pierszalowski et al., 2018). Ultimately, employing strategies like these to alleviate structural barriers to students' participation in undergraduate research will help to create a more sustainable infrastructure for inclusion in undergraduate research than relying solely on externally-funded programs.

Limitations of the Study and Recommendations for Future Research

There are several limitations of this study which are important to note. First, there are tensions associated with studies such as this that draw on relatively small samples from only one institution. Lincoln and Guba (1985) argue that the degree to which qualitative findings can be generalized to a broader population depends on the equivalence between the 'sending context', that in which the research was conducted, and the 'receiving context', that in which patterns are to be inferred. Within this framework, Lewis and Ritchie (2003) believe it is the role of the researcher to offer rich descriptions of the experiences, processes, and perceptions informing a phenomenon within a specific context and the role of the audience to judge the transferability to a larger context. A study with a larger sample (or, more precisely, a study with a larger proportion of those in the 'receiving context') will inevitably allow the reader to infer patterns to a broader population more confidently than a study with a limited sample because it has the potential to uncover a wider range of possible experiences or perceptions and better approximates the larger population (Maxwell, 2013). In other words, a larger sample allows for more equivalence between the 'sending context' and the 'receiving context' than a smaller one.

It is true that with a small sample, we may be missing important voices, experiences, and opinions that would contribute to a more accurate representation of the phenomenon. However, this does not necessarily mean that studies with a limited sample and within a singular context are not worth conducting. The tensions outlined above relate to a philosophical argument about the meaning of one's research and can be mediated by being explicit about the epistemological and ontological philosophies that guide a study (Lewis & Ritchie, 2003). Some reject the notion that there is an objective truth or singular reality to be uncovered and extrapolated to a broader population (Auerbach & Silverstein, 2003). Instead, these researchers are more concerned with understanding individual experiences and subjective realities of a few participants that inform a problem in a specific context (e.g., Carlone & Johnson, 2007; Gaxiola Serrano, 2017; Pérez Huber & Cueva, 2012; Ong, 2005). The approach used in this study aligns with a key tenet of CRT, the significance of experiential knowledge, which recognizes the importance of drawing on the experiences of those from historically underrepresented groups to explore the potential for race-based inequalities (Solórzano & Yosso, 2001). The tradition of CRT encourages researchers to seek stories of those whose voices are silenced through dominant research designs that draw patterns from majority populations (Solórzano & Yosso, 2002). Thus, we aim to fill this gap by gaining a richer understanding of the unique experiences of students of color, who are historically underrepresented in engineering. Studies like ours highlight that results do not need to be generalizable to be informative; our findings still illustrate important lessons about access and inclusion that offer valuable insight into educational inequity.

Another potential limitation relates to the design of our interview protocols. It is possible that the words and phrases that we chose to use when crafting our questions elicited some discomfort for professors and students, which caused participants to hold back from discussing certain practices, perceptions, or experiences. For example, professors may have felt pressure to respond in a certain way when they realized the study related to their interactions with students from groups underrepresented in engineering. It is also possible that students did not want to disclose certain barriers they experienced when trying to accessing undergraduate research when asked about their lived experiences. This may be especially true given that the researcher interviewing students of color does not identify as a person of color herself. Intemann (2009) makes the point that "when conducting research that involves a diverse pool of human subjects, having a similarly diverse pool of researchers will increase the accuracy and completeness of data collected" (p. 259) since the social position of a researcher can influence the way participants choose to respond to interview questions.

Finally, we acknowledge a potential bias related to who responded to our call for interviews. It is possible that professors more committed to supporting inclusion in undergraduate research experiences were those willing to be interviewed about this phenomenon, meaning we may be missing the voices of professors with less inclusive recruitment practices or those who are less comfortable discussing issues of diversity and inclusion. By only recruiting faculty who have mentored undergraduate researchers in the past, we are also missing the voices of professors who do not typically offer these opportunities to students, which represents another salient barrier to student participation in undergraduate research. Since interview participants had to email the researchers to set up a time for the interview, we may have preferentially included students who were more outgoing and felt comfortable discussing their undergraduate research experiences (or lack of them). By recruiting students in this way, we may have excluded students who were more reserved, who could have provided additional insight into how personality affects access to opportunities for undergraduate research. We may have also excluded students who do not know what undergraduate research is, which in itself serves as a significant barrier to accessing these experiences.

Very few studies have explored whether STEM undergraduates from historically underrepresented groups experience barriers when trying to access opportunities for undergraduate research. Our study makes a significant contribution to the study of undergraduate research by providing evidence that students from historically underrepresented groups in engineering may experience unique barriers to accessing undergraduate research and that access to undergraduate research in engineering may not be equal for all students. However, this study draws on a limited sample in a singular context and cannot be generalized to a broad population.

While studies with limited samples do not always warrant generalizability to a broader population, they have the potential to serve as springboards for studies that do. For instance, we contend that our study serves as an exploratory investigation that can inform larger, quantitative studies which are better positioned to determine whether findings are generalizable to a broader population, as in Cabrera (2011). Our study has revealed several themes related to barriers to accessing undergraduate research (e.g. the importance of agency/personality, the salience of intersectionality, the perceived importance of academic achievement, the significance of access to things at home like wireless internet). We recommend that educational researchers draw on these ideas to build quantitative survey instruments that more specifically, and more holistically, assess issues related to student access to undergraduate research (Johnson & Onwuegbuzie, 2004). For example, the instrument could include specific survey items that explicitly ask students whether they feel like access to internet at home or a lack of faculty role models in engineering (or other barriers highlighted in this study) have served as barriers to accessing opportunities to undergraduate research. We encourage researchers to distribute quantitative surveys that build on this work to a more extensive sample across a larger number of institutions to see how the broader population responds.

CHAPTER 5 – Conclusion

Main Findings and Recommendations for Stakeholders

Findings from the three manuscripts presented in this dissertation offer novel insights concerning access to undergraduate research. I now detail these quickly in turn.

The first manuscript provides the perspective that viable solutions do exist toward promoting more equitable access to opportunities undergraduate research. I advance research-based recommendations toward increasing the success and persistence of students from groups historically underrepresented in postsecondary STEM, explicitly through involvement in undergraduate research experiences. I offer three guiding strategies for structuring institutional diversity action plans that have the potential to promote equitable access to undergraduate research experiences and five specific tactics that institutional leaders will find attainable in relatively short time frames. Finally, I provide a questionnaire for institutional self-assessment related to these tactics.

With this manuscript, I aim to influence institutional administrators (e.g. upper administration) and policy makers (e.g. institutional- and state-level) who have the ability to make broader policy and funding decisions related to student success, by helping them see that access to transformative learning experiences like undergraduate research may not be equally accessible by all students. Specifically, I recommend that administrators and policy makers:

1. Create programming and incentives for research faculty to learn about and utilize more holistic measures of selection criteria when accepting undergraduate researchers.
2. Require cultural competency, biases, and diversity training for faculty, postdoctoral researchers, and graduate students who engage with undergraduate researchers.
3. Provide institutional funding for sustained undergraduate research programs that provide paid research experiences for students underrepresented in STEM.
4. Offer free preparatory programming regarding undergraduate research experiences for students underrepresented in STEM.
5. Integrate undergraduate research experiences into the classroom.

If promoting diversity is part of an institution's mission, considerable work will need to be done when offering undergraduate research opportunities to ensure inclusion and equity across all student groups (Pierszalowski, Vue, & Bouwma-Gearhart, 2018). The recommendations outlined above represent promising steps towards fulfilling an institution's goal of promoting diversity.

My second manuscript outlines a systematic review exploring the work that has (and has not) been done toward understanding barriers to accessing undergraduate research for STEM students of color. The 18 articles reviewed in my second manuscript yielded an extensive list of barriers to accessing undergraduate research experiences across disciplines and demographics. Most of these barriers, however, spoke to all students and did not focus on issues of access specific to students of color or specific to those in STEM fields. The authors of the articles reviewed highlighted a wide range of strategies for overcoming barriers to undergraduate research experiences for students, including curricular strategies, strategies related to marketing, strategies regarding clarifying expectations around undergraduate research, and financial and other motivational strategies for faculty participation. Of the 18 articles we reviewed, 11 mentioned implications related to the importance of broadening participation in undergraduate research. Yet we found these offerings to be lacking in detail, overly concise, and not of a critical nature. We also found a fairly limited use of theoretical/analytical frameworks across the articles. Only five articles employed theoretical frameworks and, of these, only two employed critical lenses (only one of which used the theory as an analytical tool).

Employing Cultural Historical Activity Theory as an analytical framework for this study allowed me to diagnose contradictions within, and between, each activity system (i.e. student, faculty members, institution) and enabled me to put forth a series of recommendations for ways in which transformation can occur. For example, I first recommend that faculty make a concerted effort to help students learn about opportunities for undergraduate research and employ tactics that help students feel more comfortable when interacting with them. I also call on faculty members to expand opportunities for course-based undergraduate research experiences, leverage Federal Work-Study to fund student-faculty research partnerships, and help students find a way for research hours to count toward their degree requirements.

I also recommend that academic colleges, departments, and professional discipline-specific societies help faculty shift their perceptions of which students should be allowed to engage in undergraduate research by encouraging faculty to participate in social justice workshops, trainings, or conversations that help them understand important realities like students' potential intersectionality, the difference between equality and equity, and the range and extent of personal challenges that students may experience, which may prevent the achievement of top grades and prior research experience.

Based on findings from this review, I call on institutional administrators to increase the amount of resources allocated for undergraduate research experiences (with a focus on faculty incentives, student compensation, and the development of course-based research experiences), and to devote resources to building centralized institutional or college offices with personnel devoted to helping students learn about and prepare for undergraduate research experiences. I also encourage administrators to attend to more complex structural and cultural challenges discovered via my review of literature, including revision of promotion and tenure guidelines so that faculty recognition is given for mentoring undergraduate researchers from diverse backgrounds and making an institution's commitment to inclusion explicit in the faculty hiring process, during faculty recruitment, when new faculty are first being integrated into the institution, and during annual evaluations.

Finally, in lieu of the dearth of research exploring barriers to accessing undergraduate research for students of color, I recommend that educational researchers begin to explore the set of hypotheses I put forth regarding how barriers in the way of success and persistence in postsecondary STEM may manifest as barriers to accessing undergraduate research experiences for students of color. In doing so, I recommend that researchers pay particularly close attention to the hypotheses that emphasize potential structural and institutional barriers, as these tend to represent the more complex, deep-seeded challenges that deserve dedicated attention.

In my third manuscript, I report that students from historically underrepresented groups in engineering may experience unique barriers to accessing undergraduate research (e.g. barriers associated with a lack of agency attributed to negative social experiences and barriers that are amplified by the intersectionality of identities), and that access to undergraduate research may not be equal for all students. Faculty and students made many similar claims with respect to unique barriers that students from historically underrepresented groups experience when trying to access opportunities for undergraduate research (e.g., both noted that students of color may experience challenges related to a lack of role models in engineering and that first-generation college students may not have family members who can help them navigate college experiences). However, I did diagnose an area of misalignment between student and faculty perspectives that may serve as an additional barrier to student access to undergraduate research: students' misguided perceptions about the importance of limited metrics of academic performance (e.g. high grades) towards securing participation in undergraduate research.

Based on these findings, I put forth a set of recommendations toward promoting diversity in undergraduate research experiences for three stakeholder groups: students, engineering faculty, and administrators. I recommend that students seek out and participate in organized undergraduate research programs (in addition to other student support programs) during their undergraduate degrees, as these programs provide important research-related resources and opportunities for social capital. I also recommend that students remain aware of the reality that some professors may preferentially select students that demonstrate confidence and outgoing personalities.

I recommend that engineering faculty consider the types of students they disadvantage by relying on certain selection criteria and recruitment strategies (e.g. preferring outgoing students and those who approach them in class), and employ strategies and/or rely on criteria that may be more inclusive. I also call on faculty who do not use students' grades to make decisions regarding who to accept as an undergraduate researcher to make this practice more transparent so that students can move away from the perception that their performance in classes will impact their access to research with professors. Finally, I recommend that engineering faculty who already demonstrate a commitment to inclusion in undergraduate research encourage and talk openly with their colleagues in departmental meetings or informal settings about the importance of using undergraduate research as a tool to promote diversity in STEM.

I recommend that administrators of organized undergraduate research programs consider more holistic conceptions of merit that might serve as better indicators of success in undergraduate research, considering traits like drive, personal interests, and commitment to learning (Pierszalowski, Vue, & Bouwma-Gearhart, 2018), and make these updated criteria explicit to students and faculty in order to further break down the meritocratic perception that grades are a strong predictor of access to, and success within, undergraduate research experiences. I also recommend that, when developing strategies to promote diversity and inclusion in undergraduate research experiences, both administrators of organized undergraduate research programs and institutional administrators (e.g. college deans, department heads, provosts) acknowledge the possibility that multiple barriers to accessing opportunities may exist for the same student with respect to various aspects of their identities and devise solutions accordingly.

I encourage administrators to familiarize themselves with the student demographic they are hoping to create strategies for in order to better understand the variety of challenges these students experience when trying to access undergraduate research. Finally, I call on institutional administrators to devise strategies to promote inclusion in undergraduate research that are more permanent than externally-funded organized undergraduate research programs. As noted above, various strategies for achieving this goal could include revising promotion and tenure guidelines so that mentoring undergraduates and supporting diversity is explicitly recognized (Schultheis, Farrell, & Paul, 2011), providing incentives or introducing extrinsic motivators like pressure through annual evaluations to improve mentoring and inclusion strategies (Bouwma-Gearhart, 2012), and devoting resources to the development of additional course-based undergraduate research experiences, which have been recognized as a strategy that promotes more equitable participation in undergraduate research (Bangera & Brownell, 2014; Pierszalowski et al., 2018).

Professional Direction Inspired by Dissertation

The work outlined in this dissertation is important to me both personally and professionally. Like many others, my career was jumpstarted by experiences with research as an undergraduate. This was especially valuable as a young woman and first-generation college student in a STEM field who lacked clarity about how to achieve my goal of becoming a marine mammal scientist. While I cannot know the experiences of students of color because they differ from my own, my college experience has made me empathetic toward those from historically underrepresented groups and has inspired me to better understand, and work towards eliminating, barriers that prevent students from experiencing the transformational impact of undergraduate research.

Moving forward, I have two professional ambitions that relate directly to this work. First, I plan to use this dissertation as a springboard to advance a long-term research agenda that aims to uncover inequities in access to undergraduate research experiences. I hope to extend this qualitative work with quantitative, survey-based explorations as patterns solidify from qualitative ones (Johnson & Onwuegbuzie, 2004). As a researcher, I will continue to communicate this work in a way that encourages educators and policymakers to consider strategies for eliminating barriers to access so that each and every student can enjoy the benefits of undergraduate research. Second, I will use this dissertation to promote equitable access to undergraduate research while continuing to serve as a higher education administrator. As I continue to seek positions that allow me to have a broader impact on student success, this research will help me develop and deliver effective, equity-minded programming and resources that are accessible to students across all disciplines and demographics.

Conclusion

While the benefits of participation in undergraduate research experiences have been fairly well studied (Hunter, Laursen, & Seymour, 2007; Lopatto, 2007; Russell, Hancock, & McCullough, 2007), little is known about how students come to interact with these opportunities. This dissertation offers important contributions to the study of undergraduate research experiences by helping to change the academic conversation from "*how* do students benefit from undergraduate research experiences?" to "*who* is able to access and benefit from undergraduate research experiences?" In moving this conversation forward, I have offered several novel insights, including the fact that very little research has explored barriers to accessing undergraduate research for STEM students of color, specifically, which I argue is a pressing, and largely unspoken, equity issue in higher education. I also provide research-supported evidence that students from historically underrepresented groups in engineering may experience unique barriers to accessing undergraduate research and that access to undergraduate research may not be equal for all students.

Throughout this dissertation, I have offered an extensive array of recommendations to a variety of key stakeholders. It is my hope that the manuscripts presented in this dissertation will encourage stakeholders to pay closer attention to the fact that undergraduate research experiences, widely recognized for their educational and professional affordances (Kinkel & Henke, 2006; Lopatto, 2007; Nagda, Gregerman, Jonides, von Hippel, & Lerner, 1998, 1998; Slovacek, Whittinghill, Flenoury, & Wiseman 2012), may be easier for some students to access than others. Sustaining traditions in which there is differential access to undergraduate research and its benefits is inconsistent with our national narrative to promote inclusive excellence. In presenting this work, I aim to inspire stakeholders to interrogate existing practices of student placement into undergraduate research experiences and see that viable solutions do exist toward promoting more equitable access to these potentially transformative educational opportunities.

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APPENDICES

Appendix A. The thirty-eight articles included in the preliminary, non-structured literature review which yielded ten emergent categories of barriers to success for students of color in relation to STEM at the postsecondary level.

	Reference
1	Allen-Ramdial, S. A. A., & Campbell, A. G. (2014). Reimagining the pipeline: Advancing STEM diversity, persistence, and success. *BioScience, 64*(7), 612-618.
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8	Chang, M. J., Cerna, O., Han, J., & Saenz, V. (2008). The contradictory roles of institutional status in retaining underrepresented minorities in biomedical and behavioral science majors. *The Review of Higher Education, 31*(4), 433-464.
9	Espinosa, L. (2011). Pipelines and pathways: Women of color in undergraduate STEM majors and the college experiences that contribute to persistence. *Harvard Educational Review, 81*(2), 209-241.
10	Espinosa, L. L. (2008). The academic self-concept of African American and Latina(o) men and women in STEM majors. *Journal of Women and Minorities in Science and Engineering*, *14*(2), 117-203.
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Appendix B. Search terms used to identify articles addressing barriers to undergraduate research in the structured literature review. Note that some of the papers that met inclusion criteria were identified in multiple searches.

Barrier	Search Terms	Number of Results	Date	Number of Papers Exploring Barriers in Access to UR
Barriers Associated with Lack of Representation / Role Models	“undergraduate research”, “barrier”, “students of color” + “lack of representation” + “role model” + “critical mass”	 41 225 111	 9/26/17 9/26/17 9/26/17	 0 1 0
Family and Cultural Barriers	“undergraduate research”, “barrier”, “students of color” + “cultural expectations” + “cultural norms” + “social expectations” + “social norms” + “family expectations” + “family obligations” + “dissonance” + “incongruence” + “sociocultural isolation” + “racial betrayal” + “conflicting identity” + “fragmentation” + “lack of family support” + “family pressure” + “negative peer influence”	 44 119 25 80 38 80 86 43 0 0 0 24 16 7 1	 9/26/17 9/26/17 9/26/17 9/26/17 9/26/17 9/26/17 9/26/17 9/26/17 9/26/17 9/26/17 9/26/17 9/26/17 9/26/17 9/26/17 9/26/17	 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Psychological/Psychosocial Barriers	"undergraduate research", "barrier", "students of color"			
	+ "psychosocial"	203	9/27/17	0
	+ "psychological"	459	9/27/17	1
	+ "marginalized"	299	9/27/17	1
	+ "anxiety"	271	9/27/17	0
	+ "environmental discomfort"	0	9/27/17	0
	+ "imposter syndrome"	28	9/27/17	0
	+ "conspicuous"	19	9/27/17	0
	+ "social difference"	3	9/27/17	0
	+ "non-assimilation"	0	9/27/17	0
	+ "lack of belonging"	22	9/27/17	0
	+ "unwelcome"	46	9/27/17	0
	+ "unsupported"	37	9/27/17	0
	+ "absence of social identity"	0	9/27/17	0
	+ "fragmentation"	24	9/27/17	0
	+ "self-image"	56	9/27/17	0
	+ "self-concept"	179	9/28/17	0
	+ "self-efficacy"	294	9/28/17	1
	+ "intimidation"	65	9/28/17	0
Barriers Associated with Academic Preparation	"undergraduate research", "barrier", "students of color"			
	+ "academic resources"	67	9/28/17	0
	+ "academic progress"	138	9/28/17	0
	+ "academic preparation"	267	9/28/17	0
Financial Barriers	"undergraduate research", "barrier", "students of color"			
	+ "unmet need"	13	9/28/17	0
	+ "socioeconomic"	429	9/29/17	1
	+ "employment"	466	9/29/17	3
Institutional Barriers	"undergraduate research", "barrier", "students of color"			
	+ "campus climate"	217	9/30/17	1
	+ "institutional commitment"	136	9/30/17	0
	+ "hostile"	204	9/30/17	1
	+ "chilly"	98	9/30/17	0
	+ "unsupportive"	97	9/30/17	0
	+ "institutional insensitivity"	0	9/30/17	0
	+ "competitive"	398	9/30/17	2
	+ "competition"	286	9/30/17	0
	+ "weed out"	50	9/30/17	0
	+ "lecture"	272	9/30/17	1
	+ "grading"	136	9/30/17	0
	+ "lack of community"	15	9/30/17	0
	+ "discriminatory practices"	43	9/30/17	0
	+ "discriminatory policies"	7	9/30/17	0
	+ "lower expectations"	45	9/30/17	0

Barriers Associated with a Lack of Capital	“undergraduate research”, “barrier”, “students of color” + “social hierarchy” + “social disadvantage” + “inadequate support” + “inadequate advising” + “social capital” + “cultural capital” + “mobility”	 24 3 17 4 232 182 278	 9/30/17 9/30/17 9/30/17 9/30/17 10/1/17 10/1/17 10/1/17	 0 0 0 0 1 0 2
Historical Barriers / Barriers Historically Associated with STEM Fields	“undergraduate research”, “barrier”, “students of color” + “community membership” + “media image” + “science culture” + “engineering culture” + “meritocracy” + “meritocratic”	 23 1 14 8 76 43	 10/1/17 10/1/17 10/1/17 10/1/17 10/1/17 10/1/17	 0 0 0 0 1 0
Barriers Associated with a Loss of Interest	“undergraduate research”, “barrier”, “students of color” + “loss of interest” + “real-world applications”	 14 30	 10/1/17 10/1/17	 0 0
Barriers Associated with Racism and Sexism	“undergraduate research”, “barrier”, “students of color” + “racism” + “discrimination” + “microaggression” + “antagonism” + “tokenism” + “spotlighting” + “messaging” + “stigma” + “avoidance” + “stereotype” + “outsider” + “overlooked” + “bias” + “exclusion” + “isolation”	 360 385 37 11 47 9 64 153 85 254 147 218 406 258 381	 10/2/17 10/2/17 10/2/17 10/2/17 10/2/17 10/2/17 10/2/17 10/2/17 10/2/17 10/4/17 10/4/17 10/5/17 10/5/17 10/5/17 10/5/17	 1 0 0 0 0 0 0 0 0 1 0 0 2 1 1

Appendix C. Ten categories of barriers to success for STEM undergraduate students of color resulting from the preliminary non-structured literature review.

Broad Category	Sub Category	Examples
Lack of representation / lack of role models	*Lack of representation at all levels within the college/university*	1. Lack of ethnic/cultural representation in school, faculty, class, and the curriculum, and the associated discouragement of this isolation 2. Overrepresentation in athletics 3. Not representing a critical mass or a large enough group to have a social and academic peer group with similar backgrounds
	Absence of culturally relevant role models and peers	1. An absence of culturally-relevant role models and mentors in and outside of STEM 2. Challenges with finding other students with similar backgrounds and academic experience in their majors
	Being considered to act as representatives of group	1. Being considered to speak and act as a representative of a respective group while majority peers speak and act as individuals
Family and cultural barriers	*Difficulty bridging cultural expectations and norms with expectations and norms in academia*	1. Cultural dissonance/incongruence 2. Embracing values that are not emphasized in STEM fields (e.g. activism, community engagement) means less time focused on success in STEM 3. Family obligations mean less time on campus
	Conflicting identities	1. Being ostracized by peers when one embraces values of dominant society, concern about racial betrayal 2. Having to deny culture to be accepted by peers 3. Passing as white to overcome negative perceptions of race/ethnicity 4. Separate social and academic lives can mean some students of color are deprived of benefits of sharing important information and group studying with other students
	Absence of peer/family support or excessive peer/family pressure	1. Families may question long-term goals of becoming a scientist 2. Fear of disappointing the family 3. Pressure to bring something useful back to the community 4. Pressure to contribute to the family financially, maintain the family structure, uphold family commitments, provide childcare, and uphold family ideals 5. Weakening ties to family and home 6. Peers unsupportive of academic success

Psychosocial barriers	*Exposure to stereotypes*	1. Stereotype threat or stress associated with the perception that academic performance is representative of a group 2. Concerns about deviating from traditional stereotypes 3. Being vulnerable to academic/social stereotypes of racial/ethnic/gender identities (including the perception of only being qualified for college because of affirmative action)
	Additive psychosocial effects	1. Additive psychosocial effects of belonging to more than one marginalized group for women of color 2. Layers of marginalization
	Physical side effects of psychosocial barriers	1. Time devoted to combating psychosocial barriers through social performance strategies means less time pursuing success in STEM 2. Anxiety leading to increased blood pressure and reduced working memory capacity 3. Psychological stress and social tensions 4. Stereotype threat leading to non-participation, anxiety, and underperformance
	Pressure and doubt from self and others	1. Having doubts associated with tokenism and environmental discomfort 2. Skepticism from others and oneself about qualifications and abilities to succeed 3. Anxiety that behavior might conform to negative stereotypes 4. Pressure to prove intellectual ability despite prior academic achievements (motivational and performance vulnerability) 5. Fear of failure and having to overcome negative cognitive side effects of academic setbacks 6. Interpretation of one's difficulties as a lack of ability 7. Imposter syndrome
	Feeling conspicuous	1. Gender/race/ethnicity is more salient to oneself 2. Avoiding calling attention to oneself
	Lack of belonging	1. Feelings of social difference, non-assimilation, discomfort, lack of belonging, and academic/cultural/social isolation in STEM courses, laboratories, and at the university 2. Feeling invisible, overlooked, alienated, neglected, unwelcomed, unsupported, and discriminated against (sometimes by meaningful others within science)

	Lack of identity	1. An absence of social identity due to skepticism about intellect/aptitude for scientific research and lack of community understanding/support 2. Having to employ fragmentation and/or passing 3. A sense that competence and belonging are questioned because one's body does not align with the prevalent image of an "ordinary" white, male scientist
	Feeling inadequate	1. Displays of self-doubt 2. Low confidence/self-efficacy, including career decision-making self-efficacy 3. Susceptibility to intimidation
Barriers associated with academic preparation	*Inadequate academic preparation*	1. Less access to advanced math and science courses in high school 2. College gatekeeper courses are challenging to navigate with substandard high school preparation
	Lack of resources prior to college	1. Fewer technical toys before college 2. Attended schools with fewer resources (funding, facilities, positive role models, career counselors, quality teachers, high-quality curricula, computer and internet access) 3. Larger class and school sizes in high school
Financial barriers	*High financial need*	1. Family pressure and stress regarding financing college 2. The lack of a financial "safety net" for those who change their major 3. Some likely to face unmet need, inadequate financial aid 4. A diminishing number of need-based funding for students
	Need to work	1. Many work part-time to pay for school 2. Having to skip educational opportunities to work (e.g. missing professor's office hours)
Institutional barriers	*Issues in the classroom/curriculum*	1. Professors' practice of asking questions during a lecture disadvantage those who avoid attracting attention in class 2. The promotion of competition (fostering a "survival of the fittest" and "weed out" mentality) disadvantages those facing other barriers 3. Faculty are resistant to discuss gender and race issues in classrooms 4. Lived experiences of students are not integrated into the process of learning science (difficult to identify with course content) 5. Lack of community in introductory science courses

	Campus climate	1. Misalignment of campus climate and culture 2. Some experience an unwelcoming, inhospitable, unsupportive, chilly, racial, hostile, campus and STEM climate 3. Institutional insensitivity to unique needs and experiences of students of color 4. Some face institutional discriminatory practices and policies 5. Vulnerability in institutional commitment to diversity due to tenure of university leadership
	Faculty issues	1. Some experience exclusion from informal interactions with faculty 2. Inability of professors to make science accessible and relevant to societal problems 3. Faculty rushed, arrogant, negative, inaccessible, intimidating, unapproachable, discouraging, unsupportive, and perceived to be uncaring 4. Faculty not focused on building relationship in the classroom
Barriers associated with a lack of capital	*Lack of information*	1. Some have inadequate knowledge about college life, graduate school, career paths, and STEM culture 2. Some have limited awareness of educational policies, procedures, and support programs
	Inadequate human and cultural support	1. Some have difficulty obtaining adequate advising, counseling, tutoring, education/career planning, and monitoring 2. Some lack family guidance and support when navigating college and STEM fields 3. Some have difficulty navigating social hierarchies
Historical barriers / barriers historically associated with STEM fields	*STEM cultural barriers*	1. The gendered, raced, and classed history of STEM fields 2. An incompatible media image of an engineer/scientist 3. The issue of responding to standards not traditionally intended for minority students 4. The sociocultural boundaries associated with membership in the scientific community 5. The notion that STEM is traditionally for the entitled 6. Historical laws prohibiting the entry of minorities into education and employment 7. A lack of (or token) acknowledgement of minority scientist accomplishments 8. A lack of focus on individuality and context

	STEM as neutral	1. The false notion that science is purely meritocratic and is neutral to race, ethnicity, gender 2. An insensitivity to the unique needs, experiences, and priorities of students underrepresented in STEM 3. Having to conform to the behavioral norms and appearance of white, male science culture 4. There is no approved place for discussion of class, race, ethnicity, gender, sexual orientation, or immigration status
Barriers associated with a loss of interest	*Growing disinterest in STEM*	1. Rejection of lifestyle associated with STEM 2. A belief that STEM is too technical or difficult to apply to practical, real-world issues 3. An association of STEM with words that have negative connotations, generating negative attitudes toward STEM 4. A mismatch between the student's interests and performance
	Greater interest in another discipline	1. A belief that non-STEM majors will provide greater intrinsic interest
Barriers associated with racism	*Racism*	1. Dealing with racism, discrimination, tokenism, racial antagonism, stereotypes, spotlighting, stigmatization, and prejudice
	Subtle racialized messaging	1. Perceived messaging that not having the traits of a scientist (as portrayed by dominant society) means one lacks ability to be one 2. Dealing with microagressions and subtle biases 3. Pervasive messaging in secondary schools that women and students of color lack intellectual ability to succeed in science
	Exclusion	1. Social and racial/ethnic exclusion and isolation, being treated as outsiders

Appendix D. Methodological and conceptual similarities shared among the eighteen articles included in this review.

Article	Source of data	Method	Data collection type	Discipline(s)	Positivist or postpositivist assumptions	Theoretical framework
Brew & Mantai, 2017	faculty	qualitative methods	individual interviews	does not specify, although participants come from economics/business, health, arts, social sciences, and science disciplines	no	n/a
Hirst et al., 2014	students and faculty	qualitative methods	student achievement data, questionnaires/surveys	STEM	no	n/a
Hurtado et al., 2011	students and faculty	qualitative and quantitative methods	individual interviews, focus groups, questionnaires/surveys	biomedical and behavioral science	yes	n/a
Hvenegaard et al., 2013	students, faculty, and administrators	qualitative methods	focus groups	fine arts, humanities, social sciences, and sciences	no	n/a
Jones & Davis, 2014	faculty	qualitative and quantitative methods	focus groups, questionnaires/surveys	does not specify	yes	n/a
Kierniesky, 2005	faculty	quantitative methods	questionnaires/surveys	psychology	yes	n/a
Mahatmya et al., 2017	students	quantitative methods	questionnaires/surveys	does not specify	yes	workforce diversity
Morales et al., 2016	faculty	quantitative methods	questionnaires/surveys	life sciences, social sciences, engineering, clinical/medical sciences	yes	organizational citizenship behavior, social exchange theory
Pérez Huber, 2010	students	qualitative methods	individual interviews, focus groups	social sciences, sciences	no	Latina/o critical race theory
Perlman and McCann, 2005	"departments"	qualitative and quantitative methods	student achievement data, artifact analysis, questionnaires/surveys	psychology	yes	n/a
Schwartz, 2012	students and faculty	qualitative methods	individual interviews, participant observation/ethnographic, questionnaires/surveys	STEM	no	cultural historical activity theory
Sens et al., 2017	students	quantitative methods	questionnaires/surveys	STEM and health-related disciplines	yes	n/a
Shanahan et al., 2017	faculty	qualitative methods	individual interviews	health, STEM, arts and humanities, and social sciences	yes	n/a
Spell et al., 2014	faculty	qualitative and quantitative methods	questionnaires/surveys	biology	yes	n/a

Tucker et al., 2017	students, industry leaders (employers)	qualitative methods	individual interviews, focus groups	property and construction	no	theory of students' research preparedness
van Vliet et al., 2013	other articles	qualitative methods	literature review	counselling psychology	no	n/a
Wayment & Dickson, 2008	students and faculty	quantitative methods	questionnaires/surveys, website visitation and undergraduate research participation data	psychology	yes	n/a
Wolkow et al., 2014	students	qualitative and quantitative methods	participant observation/ethnographic fieldwork, questionnaires/surveys	biology	yes	n/a

Appendix E. Faculty and student interview protocols aimed at exploring student barriers to accessing undergraduate research.

FACULTY INTERVIEW GUIDE

Introduction

Thank you so much for taking time out of your day to talk with me. As the email mentioned, I will be asking you some questions about your experiences with selecting students to participate in undergraduate research. First, I'll have you read though this consent document. Please let me know when you're finished.

So that I know you understand what you read in the consent document, can you give me general description of what you think the study is about? Are there any questions can I answer for you?

Do you give consent to participate in this audio-recorded interview?

There may be various ways to define undergraduate research. Just so we're on the same page moving forward, I consider undergraduate research to describe an experience where an undergraduate works with a faculty mentor to explore via inquiry a specific topic of interest within one's discipline. For the purpose of this interview, I would appreciate it if you only respond to experiences and perceptions as they relate to undergraduate student(s) working with a faculty mentor *outside* of a classroom or course.

Questions

1. First, I'd like to know more about your involvement with undergraduate researchers. Specifically:
    a. How long have you been mentoring undergraduate researchers at OSU or elsewhere?
    b. About how many undergraduates would you estimate you have done research with in total at OSU or elsewhere?
    c. Do your undergraduate researchers work mostly under the mentorship of a postdoc, graduate student and/or other undergraduates or do they work most closely with you?
    d. How many undergraduates are you currently engaging in research with and in what capacity?

2. Next, I'd like to know more about your process for selecting undergraduates to engage in research with you here at OSU. [If relevant] I appreciate you sharing your experiences at other institutions, however the rest of the questions relate specifically to your experiences as a faculty mentor at OSU.
    a. When an undergraduate student wants to engage in research with you, how do they typically let you know they are interested?

b. When an undergraduate student wants to engage in research with you, how do you prefer they let you know they are interested?
c. When you are looking for an undergraduate to engage in research with, how do you go about recruiting a new student?

3. Next, I'd like to know more about your criteria for selecting undergraduates to engage in research with you. Specifically:
   a. What criteria do you use when selecting an undergraduate who wants to engage in research with you? [If not addressed, ask]
   b. What specific attributes, if any, do you look for in an undergraduate who wants to engage in research with you?
   c. What specific skills, if any, do you look for in an undergraduate who wants to engage in research with you?
   d. What specific prior experiences, if any, do you look for in an undergraduate who wants to engage in research with you?
   e. What specific content knowledge, if any, do you look for in an undergraduate who wants to engage in research with you?
   f. What specific traits related to a student's emotional mood and personal feelings do you look for in an undergraduate who wants to engage in research with you, if any? [If clarification needed: This might include a student's desire to learn/motivation/attitude.]
   g. Do you make your criteria explicitly known to interested undergraduates? If so, how?
   h. Are there things you are looking for in an undergraduate that might not be part of your explicit criteria? If so, what are they and how might they affect your selection process?
   i. Can you tell me more about the undergraduate students currently engaged in research with you (or your research team)? Can you remember why you chose them? [If not addressed ask] What attributes can you remember thinking they would bring to the experience? Are any of them Honors College students? Are any of them from groups historically underrepresented in engineering? Did any of them start research with you as part of an organized undergraduate research program?
   j. Can you please describe students you have *not* selected to engage in research with? Who have you turned away and why?

4. I'd like to hear your thoughts on students' access to undergraduate research opportunities. Specifically:
   a. Do you think all undergraduates in engineering have equal access to opportunities for undergraduate research?
   b. Do you think students in engineering face any barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are?

c. Do you think **students of color** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are?
d. Do you think **women** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are?
e. Do you think **students identifying as LGBTQ+** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are?
f. Do you think **first generation college students** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are?
g. Do you think **students from a low socioeconomic status** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are?
h. Do you think **students who work while in school** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are?
i. Do you have any concerns regarding access to undergraduate research based on experiences you've had with the students you've worked with?

5. I have a few demographic questions I would like to ask before we close. Specifically:
    a. Can you please provide me with a selected pseudonym for us to use in any resulting publication in order to keep your identity private?
    b. What are your preferred pronouns?
    c. How do you describe your race and/or ethnicity?
    d. Do you consider yourself to be a first-generation college student?
    e. Do you consider any of your personal identities to be underrepresented in your discipline (e.g. childhood socioeconomic status, gender identity)?

Closing

Before we close, is there anything else you would like me to know with regard to your experiences with undergraduate research? Thank you for your time and thoughtful responses!

STUDENT INTERVIEW GUIDE

Introduction

Thank you so much for taking time out of your day to talk with me. As the email mentioned, I will be asking you some questions about your experiences with accessing opportunities for undergraduate research. First, I'll have you read though this consent document. Please let me know when you're finished.

So that I know you understand what you read in the consent document, can you give me general description of what you think the study is about? Are there any questions can I answer for you?

Do you give consent to participate in this audio-recorded interview?

There may be various ways to define undergraduate research. Just so we're on the same page moving forward, I consider undergraduate research to describe an experience where an undergraduate works with a faculty mentor to explore via inquiry a specific topic of interest within one's discipline. For the purpose of this interview, I would appreciate it if you only respond to experiences and perceptions as they relate to undergraduate student(s) working with a faculty mentor *outside* of a classroom or course.

Questions

1. First, I'd love to know more about your experience with undergraduate research. Specifically:
    a. Have you participated in undergraduate research?
        i. **IF YES** - Can you briefly describe your experiences trying to access/get involved in undergraduate research? How did you come to find out about opportunities? How exactly did you get involved (e.g., was it through an organized program, did you independently email a professor)? Did you experience any challenges related to getting involved and, if so, what were these and why do you think they arose? Were there other undergraduate research experiences you tried to get involved in but were unsuccessful? If so, can you describe those experiences? Why do you think you were unable to secure that/those research position when you tried?
        ii. **IF NO** - Have you ever tried to secure an undergraduate research experience?
            1. **IF YES** –Did you experience any challenges related to getting involved and, if so, what were these? Why do you think they arose? Were there other undergraduate research experiences you tried to get involved in but were unsuccessful? If so, can you describe those

experiences? Why do you think you were unable to secure that/those research position when you tried?

2. **IF NO** - Is research something you would be interested in doing as an undergraduate? Why or why not? What are your reasons for not trying to participate in undergraduate research?

2. Now I'd like to hear about the processes you think professors use when selecting undergraduates to do research with them. Specifically:
   a. When an undergraduate student wants to do research with a professor, how do you think the student typically lets the professor know they are interested? Why do you think this is the case? Do you have actual experience that leads you to believe this?
   b. When an undergraduate student wants to do research with a professor, how do you think the professor prefers the student lets them know they are interested? Why do you think this is the case? Do you have actual experience that leads you to believe this?
   c. When a professor is looking for an undergraduate student to engage in research with, how do you think the professor goes about recruiting a new student? Why do you think this is the case? Do you have actual experience that leads you to believe this?

3. Next, I'd love to hear your thoughts about the criteria professors use when selecting undergraduates to join their research teams. Specifically:
   a. What criteria do you think professors use when selecting an undergraduate to engage in research with them? Why do you think this is the case? Do you have actual experience that leads you to believe this?
   b. What specific attributes, if any, do you think professors look for in an undergraduate who wants to engage in research with them? Why do you think this is the case? Do you have actual experience that leads you to believe this?
   c. What specific skills, if any, do you think professors look for in an undergraduate who wants to engage in research with them? Why do you think this is the case? Do you have actual experience that leads you to believe this?
   d. What specific prior experiences, if any, do you think professors look for in an undergraduate who wants to engage in research with them? Why do you think this is the case? Do you have actual experience that leads you to believe this?
   e. What specific content knowledge, if any, do you think professors look for in an undergraduate who wants to engage in research with them? Why do you think this is the case? Do you have actual experience that leads you to believe this?
   f. What specific traits related to a student's emotional mood and personal feelings do you think professors look for in an undergraduate who

wants to engage in research with them, if any? [If clarification needed: This might include a student's desire to learn/motivation/attitude.]
   g. Can you please describe the type of undergraduate student you think professors wouldn't typically choose to engage in research with and why? Why do you think this is the case? Do you have actual experience that leads you to believe this?

4. I'd like to hear your opinion on student access to opportunities for undergraduate research. Specifically:
   a. Do you think all undergraduates in engineering have equal access to opportunities for undergraduate research? Why do you think this is the case?
   b. Do you think students in engineering face any barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are? Why do you think this is the case?
   c. Do you think **students of color** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are? Why do you think this is the case?
   d. Do you think **women** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are? Why do you think this is the case?
   e. Do you think **students identifying as LGBTQ+** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are? Why do you think this is the case?
   f. Do you think **first generation college students** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are? Why do you think this is the case?
   g. Do you think **students from a low socioeconomic status** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are? Why do you think this is the case?
   h. Do you think **students who work while in school** in engineering face any unique barriers when trying to secure undergraduate research positions? If so, what do you think those barriers are? Why do you think this is the case?
   i. Do you have any concerns regarding access to undergraduate research based on experiences you've had?

5. I have a few demographic questions I would like to ask before we close. Specifically:
   a. Can you please provide me with a selected pseudonym for us to use in any resulting publication in order to keep your identity private?
   b. What are your preferred pronouns?
   c. How many years have you been at OSU?

d. What is your class standing (e.g. freshman, sophomore, junior, senior)?
e. Which of the OSU Engineering schools/programs are you in (e.g. CBEE, MIME, etc.)?
f. Did you transfer to OSU from another college or university? If so, which one did you transfer from how many STEM credits did you transfer with?
g. How do you describe your race and/or ethnicity?
h. Do you consider yourself to be a first-generation college student?
i. Do you consider any of your other identities to be underrepresented in your discipline (e.g. childhood socioeconomic status, gender identity)?

Closing

Before we close, is there anything else you would like me to know with regard to your experiences with undergraduate research? Thank you for your time and thoughtful responses!