ASSESSING THE LANDSCAPE FOR DIVERSITY, EQUITY, AND INCLUSION EFFORTS IN U.S. STEM GRADUATE EDUCATION: A SYSTEMATIC LITERATURE REVIEW

A report commissioned by the Alfred P. Sloan Foundation

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

More resources are being poured every year into efforts to broaden participation in STEM, and foundations and other resource providers need up-to-date evidence about what works in shaping individual and organizational outcomes. This report introduces such evidence, toward enabling the Alfred P. Sloan Foundation to develop the wisest investments in STEM graduate education. We present findings from a systematic review of 228 recently published research manuscripts and evaluation reports about efforts to advance diversity, equity, and/or inclusion by race, gender, and other social identities in STEM graduate education. We reviewed abstracts of more than 500 total publications and reviewed the entirety of papers whose abstracts, titles, and/or keywords addressed at least three of the five categories: Graduate education, STEM, Race, Gender, and Baccalaureate origins. Of the 228 works reviewed, eight addressed all five; 36 addressed four of five; and 132 addressed three of five categories. Additional research has been incorporated into our review via consultations with scholars who bring expertise about specific sponsored project types, fields of study, and/or institutional types.

We find clear patterns in activities and conditions that are associated with, or that directly contribute to, positive individual, group, and organizational outcomes. We have classified these under four major themes:

- **Interventions serving individual students**: The most common type of intervention documented is programs that provide mentoring, skill development, and other resources to shift trajectories for individuals and cohorts of students from minoritized groups. Programs that provide exposure to and training in research, including bridge programs that link undergraduate and graduate education, are especially prominent in the literature. Research and a recent NASEM report offer important caveats about these interventions.

- **Institutional change efforts** reorient policy and standard practice to enhance access, diversity, and/or inclusion at the organizational level. For example, when designed well, faculty development opportunities can build capacity for making policy changes and/or improving how we evaluate and interact with students and faculty. Institutional change efforts in graduate admissions and faculty hiring may improve access to graduate education in the short term by changing practices that directly affect student opportunities. They may also change aspects of culture in the longer term in changing the mindsets, routines, and/or priorities of faculty.

- **Enhancing systems of support:** Individual and institutional change interventions are effective, in part, when they improve two fundamental aspects of graduate education: how students are selected and how they are supported in their training. Support is a critical factor, and comes through in the research as multi-dimensional: Support is 1) experienced in high-quality advising and mentoring relationships through which students learn the system and have sponsors at key junctures, 2) institutionalized in funding and other structures that ensure students have the resources to success, 3) brought to life in healthy, collaborative environments (e.g., lab, department, and discipline), and 4) critical along baccalaureate pathways into graduate education. On the last of these, the Historically Black Colleges and Universities advance disproportionate numbers of Black students into STEM graduate education through a purposeful focus on establishing infrastructure to recruit and retain students in these fields.

Reading across the themes in the literature we identified, the need for systemic change is clear. Special programs exist to support current students who are navigating the present system's barriers and cracks. Institutional change is needed because the current system reproduces inequalities by privileging students from backgrounds that are already overrepresented. And finally, support stands out as a central factor in relationships, structures, and environments alike because it is not presently the norm in STEM or higher education.

Broadly, we found programmatic interventions for individual students are covered more than institutional change efforts; more studies take individuals as their unit of analysis than organizations; and more research examines barriers to access, equity, and success than the evidence for proposed solutions. The trends we find are due, in part, to what projects are funded by foundations, which topics scholars of STEM and higher education tend to conduct research on, and which methodologies journals prioritize when publishing. **Related to these general patterns, we have identified three disconnects of research and practice across the literature we reviewed, which have potential bearing on Sloan's investment strategy:**

- **A lack of systematic data collection and analysis of program-level policies, practices, and student inputs/outcomes** prevents study of what happens (or fails to happen) in graduate programs – within and across universities and fields of study – to move the needle on diversity, equity, and inclusion. Motivating and supporting disciplinary societies and/or groups of graduate schools in broader data collection efforts would be a significant contribution.

- **Defining 'what works' through research** has been limited because it has been narrowly defined to require experimental or quasi-experimental data. Such studies require 1) designs that can be difficult to carry out in the real world and 2) statistical power that we don't have because of the very problems of underrepresentation and exclusion. Foundations can help broaden the conversation by bringing together stakeholders across methodological, disciplinary perspectives, as well as sectors such as academia, government, journals, and foundations.

- **Prioritizing implementation of recommended actions**. A third research-practice disconnect concerns barriers to change and implementing more inclusive practices. Cultures that have not prioritized diversity, equity, and inclusion as values are also less likely to prioritize implementation of recommended actions and institutional change activity that might advance these goals. Foundations can support initiatives that provide robust incentives for organizing people and organizations to change what they do.

- **A need for research-practice partnerships.** The people designing programs and change initiatives are often STEM community insiders, but the people best equipped with knowledge about the dynamics of inequality and power are often outside of STEM. Especially at the design stage, there is a disconnect between the nature of the problem and the investments being made to solve them. The W. T. Grant Foundation defines research-practice partnerships as "long term, mutually beneficial collaborations that promote the production and use of research." Foundations like Sloan could complement W.T. Grant's investment in RPP's for youth with support for partnerships that transform the late stages of educational pathways.

There is a strategic opportunity to broaden from investments that change the odds for individual students, to investments that also improve the capacity of graduate education as a whole to foster diversity, equity, and inclusion. This reorientation is one of systemic change, which "occurs when change reaches all or most parts of a system, thus affecting the behavior of the entire system" (Accelerating Systemic Change Network, 2021). A system is defined as a set of elements connected by dependencies and interactions -- internally and with the environment – that helps to achieve something. STEM graduate education is a system of humans, of practices, of rules, of institutions, which presently is directed toward training for the STEM labor market and advancing knowledge through the teaching and research work of students and faculty. However, due to how this system was originally conceived, and how it has developed, graduate education in STEM disciplines is also "achieving" an unintended but very real outcome of reproducing demographic inequalities. To make systemic change concrete, Table 1 provides examples of systemic changes that have been made or may be needed in one area of graduate education: admissions.

Table 1. Types and Examples of Systemic Change

Type of change	What makes it systemic	Examples of systemic changes made or needed in graduate admissions
Repairing broken or loosely coupled connections	System performance depends on strong connections	Griffin & Muniz (2010) found that graduate schools' diversity officers diversify applicant pools, but loose coupling between GDOs & admissions committees, combined with inequitable practices in those committees, undermine potential diversity gains.
Interrupting vicious cycles that reinforce negative outcomes & replacing with virtuous cycles of learning & improvement	Feedbacks and dependencies are inevitable; we should aim for them to be healthy, to advance our highest goals	Posselt et al (2020) describes how organizational learning combined with strong department leadership, transformed a vicious cycle of hiring and admitting mostly white, male faculty & students into a virtuous cycle of learning, equity-minded change, and demographic diversity.
Removal of corruptions or contaminants	In otherwise healthy systems, a virus or toxic behavior can quickly spread	Implicit bias research is predicated on the assumption that mitigating bias reduces inequalities because these biases are prevalent & repeatedly surface in the interactions & evaluations where 1) judgments of quality are made & 2) opportunities are distributed.
Changing rules & practices with disparate impact	Ensures that the system is not working better for privileged groups	Using GRE scores and/or attending a highly selective undergraduate institution as key, initial filters systematically undermine opportunities for minoritized students due to race-associated gaps in mean scores and college enrollment patterns by selectivity.

INTRODUCTION

More resources are being poured every year into efforts to broaden participation in STEM, and foundations and other resource providers need up-to-date evidence about the factors and forces that shape individual and organizational outcomes. The purpose of this report is to provide such evidence, toward enabling the Alfred P. Sloan Foundation to develop the wisest investments in diversity, equity, and inclusion efforts in STEM graduate education. The report presents findings from a systematic review of 228 recently published research manuscripts and evaluation reports about efforts to advance diversity, equity, and/or inclusion by race, gender, and other social identities in STEM graduate education. We reviewed abstracts of more than 500 total publications and reviewed the entirety of papers whose abstracts, titles, and/or keywords addressed at least three of the five categories: Graduate education, STEM, Race, Gender, and Baccalaureate origins. Of the 228 works reviewed, eight addressed all five; 36 addressed four of five; and 132 addressed three of five categories. Additional research has been incorporated into this review via consultations with Dr. Ann Austin, Dr. Amanda Bayer, Dr. Kenneth Gibbs, and Dr. Leonard Taylor who bring expertise about specific sponsored project types, fields of study, and/or institutional types.

As the title suggests, our focus in this report is on distilling "what works" in facilitating admission to and enrollment in MS and PhD degree programs (i.e., "access") as well as persistence, wellbeing, and graduate degree completion.[1] Bracketed out of our review is 1) literature that examines participation in professional degree programs (e.g., MD, DDS, PharmD), which come with distinctive pathways; 2) research on factors and forces that reinforce stratification and inequitable participation, which have been documented in another major research review. To be clear, the literature conveys more about stratification than what to do about it, more about barriers than how to reduce or manage them (Posselt & Grodsky, 2017). There are therefore real limitations to using published literature alone as a guide to strategy, particularly in fields like economics, where there is very little research at all to report about what reliably advances DEI. Nevertheless, the evidence from research does provide a clear portrait of factors that need to be addressed, some of which are general to STEM and others which are specific to individual disciplinary cultures and structures.

We do find clear patterns in activities and conditions associated with, or that directly contribute to, changing individual, group, and organizational outcomes. We have grouped these broadly under three major themes: Interventions serving individual students, Institutional change, and Enhancing systems of support. The most common type of intervention documented is programs whose resources or design shift trajectories for individuals and cohorts of students from minoritized groups. Often, these are designed with racially, gender, and/or socioeconomically marginalized students in mind, but rarely from intersectional or critical perspectives. There is also a burgeoning body of research on institutional change efforts that reorient policy and standard practice to enhance access, diversity, and/or inclusion at the organizational level. For example, depending upon their design and implementation, faculty development opportunities, build capacity for more equitably evaluating and interacting with students, and may be a promising tool of improving access in the short term (by changing practices that directly affect student opportunities) and changing culture in the longer term (by changing the mindsets of faculty with current theory and evidence). The vision behind institutional change efforts is well aligned with another family of factors that shapes student outcomes: the availability of advising and mentoring support for aspiring and enrolled doctoral students, supportive learning and work environments, and as well as structural supports (e.g., stable funding) that enable students to spend time on research and engage with others doing the same.

If one carefully reads across these three major themes in the data about what works, the insufficiency of the current system of graduate education for facilitating diversity, equity, and inclusion is evident. Special programs exist to support individual students who are navigating the current system's barriers and cracks. Institutional change is needed because, on its own, the current system reproduces stratification by privileging students from backgrounds that are already overrepresented. And finally, support stands out as a central factor in relationships, structures, and environments alike because student support is not presently the norm. In this way, the results of this review align with a conclusion of two recent reports by the National Academy of Science, Engineering, and Medicine: that the future of diversity, equity, and inclusion in STEM disciplines

1 A few papers speak to graduate student wellbeing or labor market transitions as outcomes, and we include those as appropriate, as well.

begins with systemic change that places students at the center of graduate education (NASEM, 2018; NASEM, 2021).

A caveat to readers: The efforts presented here reflect field-wide selection bias. They have received funding and institutional support, and they have been implemented, evaluated, and published. They are a product of systematic preferences for certain kinds of activities, research questions, and analyses. In addition to looking to published efforts, then, it is also worth paying attention to what is missing or underrepresented altogether from the literature and broader landscape of investment in DEI in STEM. For example, we have noted a dearth of analyses about institutional accountability and organization-level analysis more broadly. Another prominent silence in the literature surrounds analysis of social identities other than race and gender (e.g., sexual orientation, disability status, religion) and serious analysis of intersectional dynamics among social identities. There is also little longitudinal analysis of either individuals or organizations or generalizable quantitative research that uses large-scale data or methods that permit causal inferences. This is partly due to the highly decentralized nature of graduate education – by disciplines/fields of study, by universities, and even within universities. Scholars in academic and non-profit sectors are in active discussions about how to improve the availability of data at the program level and over the course of students' pathways.

MAJOR FACTORS AFFECTING ACCESS AND/OR SUCCESS

Although much remains to be tried, tested, and analyzed across contexts and at scale, there is also much to report that can inform Sloan's strategy in this area. In the sections that follow, we summarize families of factors that affect the access and success of students of minoritized backgrounds in STEM graduate education. Then, we present an analysis of major cross-cutting themes in the literature that carry implications for the Sloan Foundation and other investments in DEI in STEM graduate education going forward.

INTERVENTIONS SERVING INDIVIDUAL STUDENTS

In fields where there has been considerable research, attention has predominantly been on building diversity of graduate students and the labor market through interventions that shape individual student pathways. Programs that serve individuals or cohorts of students to enhance their opportunities and odds of success in the current system tend to be multifaceted in the services they provide and the skills they develop. For example, undergraduate and graduate training programs at the National Institute of General Medical Science "are designed to equip trainees with the technical (e.g., appropriate methods, technologies, and quantitative/computational approaches), operational (e.g., independent knowledge acquisition, rigorous experimental design, and interpretation of data) and professional (e.g., management, leadership, communication, and teamwork) skills required for careers in the biomedical research workforce" (NIGMS, 2021). Programs like these are more prevalent than public policy interventions or efforts to change the structures and cultures of graduate education. They tend to have a positive record for the students who have access to them, though few evaluations control for selection into them, permit causal inferences, or offer analyses about what mechanisms and programmatic features are reliably producing specific impacts.

RESEARCH EXPERIENCES SUPPORTING SCHOLARLY SOCIALIZATION

Research and other hands-on experiences for aspiring STEM scholars are crucial tools of socialization (i.e., learning culture). Obtaining experience during the undergraduate years can be pivotal to choosing careers in STEM (see, for example, Borum and Walker (2012) on Black women's career choices in mathematics) and to being considered by graduate admissions committees as a viable candidate (Posselt, 2016). Research experience for graduate students builds skill and a presentations and publications that are currencies in the STEM labor market, and provide role modeling and practice in navigating academic systems and transitions within it, from a combination of peers & faculty. Among different models of structured research experiences, there appears to be potential in both cohort-based influence and cross-generational influence; a successful set of programs carried out by the National Institutes for Health, the McNair Scholars Program, and the Meyerhoff Scholars Program highlight these patterns. These programs build community, skills, and knowledge, so that students' potential as scholars is recognized with the system's current currencies.

The access that undergraduate and graduate students of color have to intensive, hands-on research experiences is critical to their success and subsequent entry into faculty and other research careers. Among the findings of a recent NASEM (2017) consensus study on undergraduate research experiences (URE), the panel concluded, "Studies focused on students from historically underrepresented groups indicate that participation in UREs improves their persistence in STEM and helps to validate their disciplinary identity." At the undergraduate level, students report positive relationships between receiving opportunities to engage in faculty-led research, their desire to pursue graduate education, and their successful program completion (Fifolt, 2014). At the doctoral level, minoritized students who can engage in their studies full- or nearly full-time experience higher rates of engagement in the hands-on research experiences linked to their subsequent pursuit of research-intensive roles. Those who must work in roles unrelated to their studies are often unable to participate in such supplemental activities as publishing, participating on research teams, and attending professional conferences (Crumb et al., 2020). Institutions must find ways to financially support minoritized students' ability to engage in these opportunities (e.g., through seed money grants, exposure to funding agencies, etc.). Structured research engagement and preparation also have affective outcomes and may prevent a self-fulfilling prophecy: students who feel less prepared in their undergraduate and graduate studies end up feeling less successful relative to their peers and end up publishing less (Fisher et al., 2019).

In addition to citing an array of benefits that accrue to students through research experience, the 2017 NASEM report also issues caveats, specifically around the need for research supervisors to receive professional development in mentoring, for rigorous evaluation of such programs, and for collaboration within and across institutions to develop evidence-based improvements to the design of undergraduate research experiences.

BRIDGE PROGRAMS

The literature suggests that bridge programs, which we operationalize as programs that purposefully connect undergraduate and master's programs to doctoral education, can be important mechanisms for the enrollment and success of students from marginalized backgrounds in STEM. Underlying their design is an interest in reducing the jagged break between undergraduate and graduate education, ensuring graduate programs see students with different backgrounds than their usual as viable candidates for graduate education, and/or providing an opportunity to supplement student learning to date with coursework, research, and/or mentoring in a more focused setting over 1-2 years.

Researchers have studied a number of nationally known bridge programs, including the Fisk-Vanderbilt Masters to PhD Bridge Program (Stassun et al., 2011; Stiner-Jones & Windl, 2019), Meyerhoff Scholars Program (Maton et al., 2016), the Cal-Bridge Program (Rudolph, 2019; Rudolph, Holley-Bockelmann, & Posselt, 2019), and the Sloan Indigenous Graduate Partnership (Johnson et al., 2017). These programs enhance opportunities and outcomes for minoritized students pursuing graduate STEM education. Specifically, the literature suggests that bridge programs may enhance students' sense of community (Maton et al., 2016), facilitate opportunities for faculty mentoring and support (Chow-Garcia, 2016), and provide the insight necessary to navigate the "hidden curriculum" often associated with completing gatekeeping courses, obtaining funding, and applying to PhD programs (Stassun et al., 2011). For one of the first and most well-conceived bridge programs – one which includes a strong MSI-PWI partnership structure and a thoughtful analysis of underlying mechanisms that enable students' success, we recommend Stassun, et al. (2011) on the Fisk-Vanderbilt Masters to PhD Bridge Program.

Much of the published work in this area is evaluative more than research-based or empirical; often it is written by people evaluating their own program. However, two studies using comparison group analysis do suggest that, all else being equal, students who choose to enroll in bridge programs complete the doctorate at higher rates than those who do not (Maton et al., 2016; Whittinghill et al., 2019). Bridge programs may minimize the impact of disciplinary norms that often negatively impact students of minoritized backgrounds in graduate STEM education; however, there has yet to be research that documents a popular claim that bridge programs nudge the cultures of the departments or disciplines in which they are located.

INSTITUTIONAL CHANGE EFFORTS

A second class of interventions aims to change outcomes for individual students and organizations by changing the policies, practices, and ideas that govern graduate education. In this change work, the literature highlights a critical role for learning on the part of both individuals (often through professional development) and for organizations (often through collaborations with graduate schools and/or disciplinary societies).

CHANGING INSTITUTIONAL POLICIES AND PRACTICES

Some established policies and standardized operating practices, while facially neutral, present disparate impact for minoritized students – impeding their access to and/or full participation in graduate education and research. Directly changing these policies, therefore, can reduce barriers

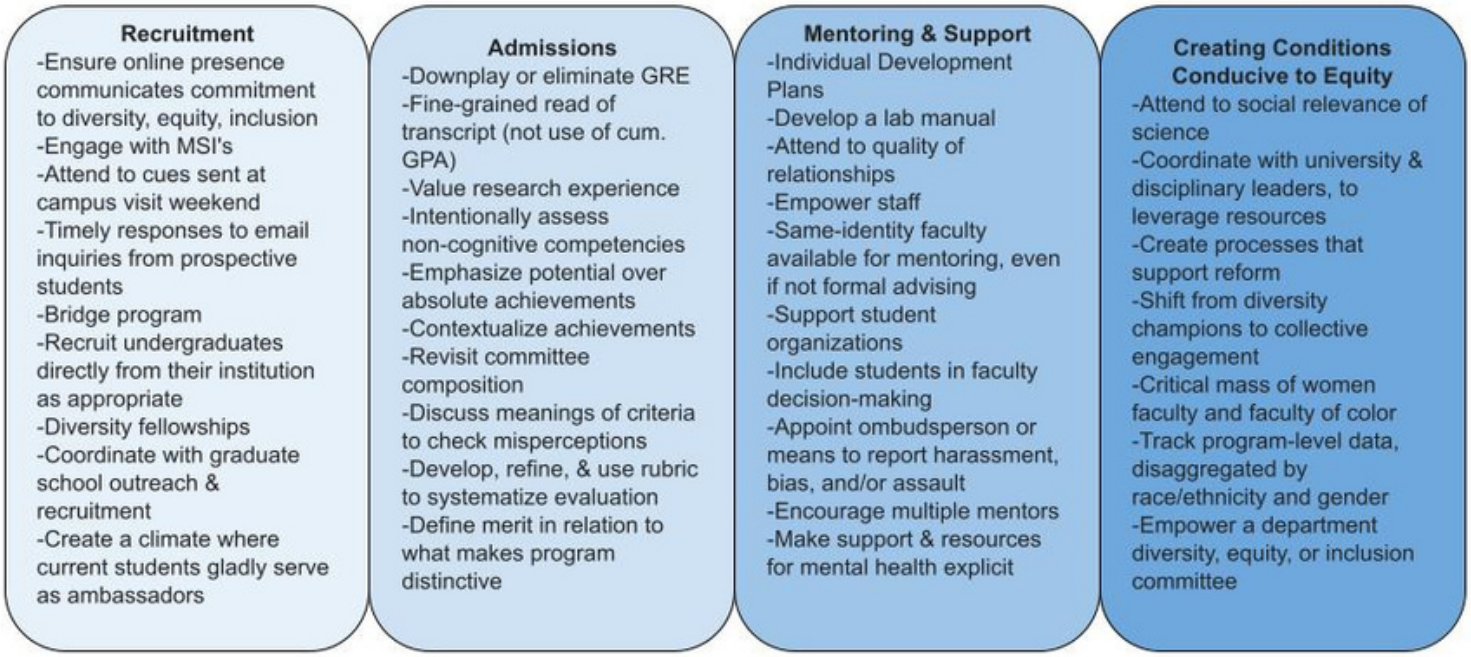
and create a more level playing field. Two common areas of policy change that may impact the composition and inclusion of graduate students from minoritized backgrounds are 1) faculty hiring which affects the landscape of mentoring and student support (e.g., Burt et al., 2018; Corbett & Hill, 2015; Posselt et al., 2018), and 2) graduate admissions, where standard requirements such as the GRE and/or implicit biases perpetuate unequal access (Eaton et al., 2020; Miller & Stassun, 2014; Posselt, 2016; Potvin et al., 2017). Underlying both of these ostensibly "meritocratic" policy processes are conceptions of academic excellence whose typical definition may be too narrow to capture the diversity of strengths needed to serve a broader population than the academy has typically employed and educated.

Generalizable evidence for the specific impact of GRE-optional admissions on changing diversity of specific programs and fields is still emerging, but there is more than a decade of research indicating that holistic admissions is a critical component of a broader suite of efforts to align policy and practice with the assets and needs of minoritized students (Stassun et al., 2011; Wilson et al., 2018; Posselt et al., 2017; Posselt 2020). And, more research is emerging every year about the value of test-optional, no-test, and otherwise holistic admissions processes in diversifying who is admitted to undergraduate institutions (e.g., Bastedo et al., 2018;Bennett, forthcoming). Often, implementing more holistic approaches to admissions also involves changing application processes. Whittington et al. (2017) found, "our revised application process captured applicants with high commitment to the PhD, and their previous or gained experiences in addition to their OGR experiences increased their self-confidence, research self-efficacy, and likely their science identity to pursue the PhD. This increased confidence along with their cumulative training experiences enhanced their profile and increased their admission to PhD program." In systematically changing what they ask for and look for in applications (i.e., behaviors) as well as moving toward contextualized, potential-oriented, and equity-minded in how they read information (i.e., mindsets), departments change the cultures of evaluating who "merits" admissions.

In addition to hiring and admissions, additional policies and practices may support the advancement of students of color and women. These include qualifying and candidacy exams (either the structure of the exams per Liera, 2021 or structures of preparation for the exam per Wilson et al., 2018), and financial aid (described in greater detail below). Mendoza-Denton et al. (2017) found an important role in STEM PhD programs for recruitment and retention practices, including "a visible commitment from institutional administrators, targeted scholarships, strong mentoring, and systematic benchmarking of both student progress and institutional goals." Following a comparative case study of several high-diversity STEM PhD programs, Posselt (2020) identified a common set of recruitment, admissions, and mentoring and support practices (Figure 1). Notably, these programs also engaged in specific practices to create organizational conditions that would be conducive to future changes and continued diversity work, such as systematically tracking demographics in a variety of student milestones, actively attending to the relevance of their disciplines for social problems and coordinating with institutional and disciplinary leaders around broader efforts toward diversity, equity, and inclusion. Normalizing such activity sets the stage for organizational learning toward systemic and cultural change – rather than episodic, discrete "reform" efforts (Posselt et al., 2018; Posselt, 2020).

Figure 1: Inclusive Practices in High-Diversity STEM PhD Programs

(copied with permission from Equity in Science: Representation, Culture, and the Dynamics of Change in Graduate Education)



Adapted from Posselt, 2017

LEARNING AND PROFESSIONAL DEVELOPMENT

The means of learning that supports long-term institutional change often involves professional development, for individuals and/or organizations. Given the paucity of most current professors' prior learning on change management – and equity, diversity, and inclusion broadly – professional development and training – is a critical tool for changing practices and developing skills for serving racially minoritized and women-identified graduate students. Embedding such learning in graduate programs themselves and expecting ongoing learning of faculty represents a cultural shift away from the notion that research training is the sole domain of expertise that scholars should have. Specifically, the literature suggests that opportunities for doctoral students to engage in professional development related to mentoring may enhance their ability to create supportive relationships with students later, as professors themselves. As many STEM-focused pathway initiatives emphasize training in research skills, Fifolt et al. (2014) suggest that, despite feeling prepared to conduct research, many junior scholars feel ill-equipped to support their own advisees with historically marginalized identities.

Professional development that focuses on mentoring and advising will in many cases need to become more sophisticated about the dynamics of culture and identity. To support the cultural integrity of students with marginalized backgrounds, professional development should be thoughtfully designed to acknowledge both the history and present cultures of STEM disciplines and the cultures of students, including diverse ways that students embody and express their racial and gender identities. For example, Ruiz (2013) advocates for the integration of critical race and "ethno-mathematics" pedagogical techniques that (1) ground mathematics in students' lived

experiences and cultural backgrounds and (2) explicitly address and challenge racism and other forms of oppression. Other scholars have specifically examined how professional development in mentoring Indigenous students can raise awareness about both the expression and salience of Indigenous identity (Windchief & Brown, 2017) as well as "ways to assist AI/AN students who are navigating the culture of STEM fields — a culture that can be at odds with students' ways of being and knowing" (Brown & Komlos, 2019). When faculty have training & other professional development support, they are better equipped to support student success, to create belonging and community for students whose backgrounds are different from their own, and perhaps, to begin rethinking the norms of the environments in which they have the leadership to shape the culture.

ENHANCING SYSTEMS OF SUPPORT

The individual and institutional change interventions described to this point are worthy, in part, because they improve two fundamental aspects of graduate education: how students are selected and how they are served and supported. These practices carry implications for diversity, equity, and inclusion through their correspondence to core sociocultural mechanisms of evaluation (which shapes the distribution of access, resources, and other opportunities) and interaction (which shapes social bonds, individual wellbeing, and possibilities of collective action). In this section, we synthesize evidence that collectively indicates support is multi-dimensional. Students experience it in supportive advising and mentoring relationships. Support is also institutionalized in structures such as financial aid, and it is brought to life in supportive environments *e.g., lab, department, and discipline). Finally, we close the substantive findings of our review with a discussion of the supports along baccalaureate pathways that speak to the importance of institutional contexts as the prologue to the pursuit of graduate education in STEM.

ADVISING AND MENTORING SUPPORT

It is hard to overstate the importance of high-quality advising and mentoring, which is consistently cited as one of the best predictors of graduate student success (Brunsma et al., 2016). The importance of mentoring begins in college. Cole & Griffin (2013) find that the role of mentors at the undergraduate level is to enable students to appreciate their potential and provide preparation and support in the transition to graduate school. Burt et al. (2018) concur, that "interactions with undergraduate mentors can boost participants' confidence in their ability to do well in graduate school." Mentoring has also been identified as a critical mechanism within high-quality undergraduate research experiences and bridge programs, such as Cal-Bridge, which is unique in providing each undergraduate from a California State University with a mentor from their campus and one from a University of California campus (Rudolph et al., 2019).

Students who view their advising relationships positively also hold more positive views of their discipline and have a shorter time to degree (Zhao et al., 2007). The nature of interactions in these relationships provides some of the exposure to academic and disciplinary cultural norms and practices that a rising scholar might have (Margolis & Romero, 1998). Although graduate education has long been described as a process of developing progressive independence, it is through the scaffolding provided via advising and mentoring that undergraduate and graduate students — especially those who are the first in their family to go to college or graduate school — develop

professional skills and dispositions. Lovitts & Nelson (2000) found that the quality of a faculty-student relationship is the single strongest determinant of whether a student will complete the PhD. However, recent research has also uncovered critical roles for network-based mentoring and peer mentoring, particularly for racially/ethnically minoritized students and women of all backgrounds in academic settings that lack these forms of diversity (Rockinson-Szapkiw et al., 2021; Spalter-Roth et al., 2013).

Research on successful mentoring practices for African American students finds that it introduces perspective and support through which African American scholars can reconcile apparent conflicts between the values of the academy and those with which they were raised (Antony & Taylor, 2001; Gopaul, 2011; Margolis & Romero, 1998; Taylor & Antony, 2000). Mentors also support African American students' socialization by acquainting them with professional and field-level norms, while also encouraging them to hold fast to their personal values (Antony, 2002). Research has suggested that these relationships need not be dyadic. Multiple mentors (including faculty, peers, staff, and family) can confer benefits of "developmental networks" (Baker & Lattuca, 2010), such as appreciation for nuances in academic norms and variations in approaches to support.

Particularly when available from multiple sources in multiple forms, strong mentorship is essential for the success of minoritized graduate students in STEM. As mentors, faculty can provide support by developing students' research skills (Mills et al., 2019), countering negative stereotypes about racially minoritized and women-identified students (Clark et al., 2016), and coaching students through their journey to the professoriate (Kim-Prieto et al., 2013). In a phenomenology aimed at delineating how STEM PhD students from underrepresented backgrounds defined "support" from faculty, one of the three most important themes was faculty mentors' ability to speak openly and honestly about the racialized and gendered aspects of academia (Posselt, 2018).

While cross-race and cross-gender mentoring relationships can benefit minoritized students (Foerscht, 2019; Horsford, 2014), several studies highlight the importance of shared racial and gendered identities between students and their mentors (Borum & Walker, 2012; Chow-Garcia, 2016; Rogers, 2018; Zeligman et al., 2015). Their presence alone also signals to students from marginalized backgrounds that they, too, can persist and achieve success in their academic program and career (Castro, 2018). However, several scholars note the lack of a critical mass of minoritized faculty to mentor students, suggesting a structural inequity with potential consequences for minoritized students who might benefit from shared identities in their mentoring relationships (Castro, 2018; Foerscht, 2019; Horsford, 2014; Kong et al., 2013; Zelingman et al., 2015). Others have commented on the need to improve access to and the quality of mentoring, writ large — regardless of whom it is coming from. As described above, faculty professional development that builds mentoring capacity can be thought of as a move toward institutional change.

FUNDING AND OTHER STRUCTURES OF SUPPORT

Providing funds to students is crucial to the enrollment and retention of racially minoritized and women-identified graduate students in STEM; however, funding alone is unlikely to reduce disparities. In their discussion of approaches to enhancing equity in graduate education, Ong and colleagues (2011) stress the significance of efforts to heighten students' awareness of the various opportunities for funding that exist. Relatedly, programs and institutions must be positioned to coach racially minoritized and women-identified students through the process of identifying and applying for funding opportunities, both internal and external. The authors also acknowledge the role of systemic inequities in external funding, evidenced by the significantly lower rate of fellowship awards received by racially minoritized women, even after controlling for various academic characteristics, such as grade point average. In sum, institutions and programs must demonstrate a commitment to the financial support of minoritized students (Reichert & Absher, 2013) and implement tools aimed at institutional accountability related to their success (Mendoza-Denton et al., 2017).

SUPPORT ALONG BACCALAUREATE PATHWAYS

Baccalaureate pathways have an important role in the ultimate attainment of a graduate STEM degree for racially minoritized and women-identified students (Ong et al., 2011; Slovacek et al., 2012; Starobin & Laanan, 2010; Suitts, 2003). As the 2020 American Institute for Physics TEAM-UP report comprehensively analyzed for the physical sciences, systemic changes required to diversify the scientific workforce begin with baccalaureate attainment (AIP, 2020). Much can be learned from Historically Black Colleges and Universities (HBCUs) and community colleges about attracting STEM undergraduate majors and earning their ongoing commitment by creating supportive work and learning environments. HBCU's successfully graduate a disproportionate number of underrepresented students who go on to pursue STEM graduate education.

Despite representing just three percent of U.S. higher education institutions and having comparatively smaller endowments (privates) or receiving fewer state appropriations (publics), HBCUs consistently graduate high percentages of Black students who eventually earn STEM doctoral degrees (Upton & Tanenbaum, 2014; Strayhorn et al., 2012). In 2010, 19% of Black students who received a STEM bachelor's degree graduated from an HBCU (Gasman & Nguyen, 2014; Upton & Tanenbaum, 2014). By 2010, nearly one-third of all Black students with a bachelor's degree in mathematics and statistics attended an HBCU; the percentage of Black students with a degree in the physical sciences from an HBCU was slightly higher still at 37% (Gasman & Nguyen, 2014; Upton & Tanenbaum, 2014). While Black students constituted only two percent of all STEM doctoral degree holders in 2009, HBCUs generated approximately one-tenth of this population, again, despite only representing three percent of colleges and universities (Upton & Tanenbaum, 2014). Studies suggest their success in this regard is due to "deliberate efforts to establish an infrastructure to recruit and retain students in these fields" (Ong et al., 2011). A study of Black women mathematicians' pathways from undergraduate education in HBCUs to graduate education in research universities found that women benefited from HBCUs' close-knit learning environments, which supported their self-image and identity development (Joseph, 2012). Other studies also find that the inner strengths cultivated in HBCUs prepare Black students to navigate racism in graduate education and beyond.

Although historically denigrated in the postsecondary education system, community colleges have much potential to broaden participation and enhance equity in STEM graduate education, due to their disproportionately high enrollment of racially minoritized, low-income, and first-generation students (Terenzini et al., 2014; Wang, 2013). While community college students in STEM baccalaureate programs are less likely than their four-year counterparts to complete a STEM degree, numerous studies suggest that community colleges may uniquely position minoritized students to enroll and excel, through curricular pathways specifically designed for transfer into baccalaureate STEM programs (Bahr et al., 2017; Beede et al., 2011). More empirical study of community colleges' role is needed (Wang, 2013). For example, despite growing interest in community colleges as potential pathways into STEM graduate education, scholars and policymakers have yet to link such questions as how many students are enrolled in STEM coursework at community colleges, factors that shape their transition into a baccalaureate STEM program, and underlying conditions that inform that their enrollment into graduate STEM programs (Bahr et al., 2017; Starobin & Laanan, 2010; Starobin et al., 2013). Questions like these need to be addressed in combination, as part of a systemic approach to strengthening baccalaureate pathways to graduate education.

CONCLUSIONS AND RECOMMENDATIONS

Across the literature, more programmatic interventions for individual students are covered than institutional change efforts; more studies take individuals as their unit of analysis than organizations; and more research examines barriers to access, equity, and success than the evidence for proposed solutions. The first trend is explained in part by the fact that, until recently, there have been few institutional, cultural, or systemic change initiatives in graduate education at all; graduate education continues to be deeply decentralized and left to individual PhD programs and faculty to carry out, with little accountability. And, because many of the published interventions for students have been examined more from a standpoint of program evaluation than of research, there is relatively little social science about these interventions or their underlying mechanisms.

Related to these general patterns, which have potential bearing on Sloan's investment strategy for effecting sustainable change in STEM graduate education, we have identified four disconnects of research and practice across the literature we reviewed. These, too, may be able to help inform Sloan's approach in the years ahead. In the section that follows, we briefly describe those research-practice disconnects and offer several recommendations and principles for an investment strategy that is responsive to the changing landscape of activity and evidence surrounding DEI in STEM graduate education.

RESEARCH-PRACTICE DISCONNECTS THAT SLOAN CAN BRIDGE

A Need for Program-level Data. As discussed above, there is more information about individual pathways than the behavior of graduate education organizations. And more studies document barriers to access & success, including experiences with racism, sexism, and intersectional oppression, than documenting what works. We see two reasons for this that have implications for Sloan: First, the decentralized nature of graduate education means that, other than the expectation to report very basic data in the Integrated Postsecondary Education Data System, there is no incentive for graduate programs to collect or report information in a common way across fields and institutions. Motivating and supporting disciplinary societies and/or groups of graduate schools in broader data collection efforts would be a significant contribution, for as they say, you cannot change what you cannot assess.

Defining 'What Works' through Research. Second, and related to the question of assessment, generalizable research about "what works" in practice has been limited because it has been narrowly defined. It rests on an intellectual paradigm that is often understood to require experimental or quasi-experimental data, as exemplified by the standards for inclusion in the "What Works" Clearinghouse (WWC, 2021). Academic journals, too, privilege experimental and quantitative evidence, and of course, the impulses to privilege quantitative and experimental evidence are similarly --and understandably-- strong in STEM. The problem is that these studies require 1) designs that can be difficult to carry out in the real world and 2) statistical power that we don't have because of the very problems of underrepresentation and exclusion. An understanding of inequities as created by and experienced at the nexus of multiple systems of oppression (i.e., an intersectional analysis) compounds this challenge; groups of individuals with specific combinations of underrepresented identities are even harder to study in the aggregate. It can also be extremely difficult to study the efficacy of multi-faceted and/or systemic change efforts which may have multiple "treatments" in play simultaneously. Sloan can help broaden the conversation about how we define and track stasis and change in diversity, equity, and inclusion. The foundation can support events that bring together from diverse methodological and disciplinary perspectives, as well as different sectors such as academia, evaluation, journals, and foundations. Together, they may set a course for understanding and disseminating what works that is perhaps broader than that of the What Works Clearinghouse, while still upholding high intellectual standards.

Prioritizing Implementation of Recommended Actions. A third research-practice disconnect concerns barriers to implementing more inclusive practices and supporting change processes. Cultures that have not prioritized diversity, equity, and inclusion as values are also less likely to prioritize implementation of recommended actions and institutional change activity that might advance these goals. The fields of economics and astronomy, for example, have a growing number of reports about the problems of inequity, but they lack resources or incentives to move on implementing the reports' proposed solutions. Examples include two national reports on thes state of economics (which are described in Amanda Bayer's annotated bibliography), the AIP TEAM-UP report on African American baccalaureate attainment, the American Astronomical Society's Task Force on Diversity and Inclusion, two Inclusive Astronomy reports, and the NASEM Graduate STEM Education for the 21st Century report. Who will organize and support change agents and leaders in

these disciplines to implement these recommendations and study their effectiveness? Sloan can support initiatives that provide robust supports or incentives for organizing people and organizations to change what they actually do.

A Need for Research-Practice Partnerships. A final, general disconnect between research and practice that is noteworthy based on our review is that the people designing programs and change initiatives are often community insiders, but people who are best equipped with knowledge about the dynamics of inequality and power are outside the community. Therefore, there is a disconnect between the nature of the problem and the investments being made to solve them. Particularly at the design stage, we need more collaborations between scholars of DEI and those who want to make a change in their communities, respecting the distinctive perspectives that each stakeholder group holds and the inevitable need for translation across those perspectives (Posselt, 2020). The William T. Grant Foundation defines research-practice partnerships as "long term, mutually beneficial collaborations that promote the production and use of research," and it has prepared a series of tools for prospective grantees. Sloan has an opportunity to complement W. T. Grant's focus on projects for youth with support for RPP's in transforming the late stages of educational pathways and into research careers and the professoriate.

RECOMMENDATIONS FOR SYSTEMIC CHANGE

To shift from investments that change the odds for individuals to investments that also improve the capacity of graduate education as a whole to foster diversity, equity, and inclusion will require systemic change, which "occurs when change reaches all or most parts of a system, thus affecting the behavior of the entire system" (Accelerating Systemic Change Network, 2021). A system is defined as a set of elements connected by dependencies and interactions -- internally and with the environment -- that helps to achieve something. We can think of STEM graduate education as a system (of humans, of practices, of rules, of institutions), which presently achieves two official outcomes: training for the STEM labor market and advancing knowledge, via organizing students who gain knowledge and a credential but who also serve important teaching and research assistance roles for faculty.

However, because of how this system was originally conceived, and how it has developed over time, graduate education in STEM disciplines is also "achieving" an unintended but very real outcome of reproducing demographic inequalities. When we consider that graduate education is comprised of sets of interconnected actors (e.g., students, faculty, administrators), practices (e.g., recruitment, admissions, training, mentoring), institutional types (e.g., community colleges, minority serving institutions, research universities), and organization types (e.g., higher education institutions, foundations, research labs), the scope of the challenge becomes clear. Add to this the distinctive meanings of "diversity, equity, and inclusion" as goals, the distinctive needs of students from different groups, the roles of micro interactions, meso practices, and macro tendencies that all might be identified as problematic presently and the complexity associated with the system's improvement may seem overwhelming. No single effort will be able to touch all of these; therefore, how we define the part of the graduate education system that we are trying to improve becomes a strategic imperative.

Indeed, as the new Sloan Equitable Pathways grant program reveals, to think systemically is more than thinking bigger. Instead of paying attention only to the improvement or performance of parts of a system and what they are connecting, it means paying attention to sets of parts, the connections between them, and how they are aligned with collective purpose. We begin to ask questions like, how can we ensure that STEM graduates of MSI's have the opportunity to enroll in predominantly white research universities for graduate programs? How are DEI as values aligned with the training and knowledge advancement aims of graduate education described above? How might bridging the research-practice disconnects cited above interrupt the reproduction of inequalities? How can we nudge the sets or meanings of key values in the minds of STEM community members toward equity, so scientists living out the community's values will support equity? Table 1 portrays how changes with systemic effects can take a variety of forms, and provides examples of how they might be applied in thinking about improving graduate-level admissions.

Table 1. Types and Examples of Systemic Change

Type of change	What makes it systemic	Examples of systemic changes made or needed in graduate admissions
Repairing broken or loosely coupled connections	System performance depends on strong connections	Griffin & Muniz (2010) found that graduate schools' diversity officers diversify applicant pools, but loose coupling between GDOs & admissions committees, combined with inequitable practices in those committees, undermine potential diversity gains.
Interrupting vicious cycles that reinforce negative outcomes & replacing with virtuous cycles of learning & improvement	Feedbacks and dependencies are inevitable; we should aim for them to be healthy, to advance our highest goals	Posselt et al (2020) describes how organizational learning combined with strong department leadership, transformed a vicious cycle of hiring and admitting mostly white, male faculty & students into a virtuous cycle of learning, equity-minded change, and demographic diversity.
Removal of corruptions or contaminants	In otherwise healthy systems, a virus or toxic behavior can quickly spread	Implicit bias research is predicated on the assumption that mitigating bias reduces inequalities because these biases are prevalent & repeatedly surface in the interactions & evaluations where 1) judgments of quality are made & 2) opportunities are distributed.
Changing rules & practices with disparate impact	Ensures that the system is not working better for privileged groups	Using GRE scores and/or attending a highly selective undergraduate institution as key, initial filters systematically undermine opportunities for minoritized students due to race-associated gaps in mean scores and college enrollment patterns by selectivity.

As the table makes clear, systemic change is aligned with institutional change efforts in focusing attention on changing the system that serves students. However, in this time where students are navigating a fraught system, we believe that there is a clear case to balance investments in institutional and systemic change with investments that more directly serve students. Indeed, systemic change offers a way to see our themes in relation to one another. Although most of the

literature and program evaluations that we read were focused on the case for one factor, intervention, or variable at a time, it is possible to envision the three major types of effective strategies for diversity, equity, and inclusion we found not in isolation but as interconnected. The NSF-INCLUDES Alliance- Inclusive Graduate Education Network is an example of a cross-sector effort that brings together foundation support, disciplinary societies, national labs, universities, and other organization with an agenda of mutually- reinforcing interventions for students and institutional change efforts that develop, refine, and institutionalize inclusive practices.

Finally, across awards and activities, there are opportunities for Sloan to coordinate its activities as well. An internal 'theory of change' for its investments and its relationships with other people and organizations in the STEM and DEI landscapes could be used to guide and synchronize how it allocates resources, prioritizes activity, and coordinates staff and supported PI's toward common ends. Evolving leadership of UCEM and SIGP sites into a more purposeful community of practice as change agents would be one way to coordinate for collective capacity. And Sloan's involvement in the Science Philanthropy Alliance is one potential mechanism for working across foundations, as were conversations initiated at the May 20 Funders' Roundtable.

Underlying systemic change is the basic tenet that we are all interconnected, and that actions by any of us can affect all of us. Quantum theory was rooted in the revelation that we are part of the reality that our science strives to understand-- that our scientific tools and instruments define what we recognize as reality. Applied to the social dimensions of science, it is clear that we are also part of the organizational realities we are trying to change in STEM graduate education (Posselt, 2020). It draws our attention to ways that the scientific enterprise is of our own making, and that its future is up to all of us to co-create.

ADDITIONAL PRINCIPLES FOR TRANSFORMATIVE INVESTMENT STRATEGIES

Grounded in findings from the empirical literature, and with a framework of systemic change as a means of acting on what we have learned from the literature review, we close by offering selected additional principles that may be useful to Sloan staff and other actors in the philanthropy landscape as they update their investment strategies and align them more closely with activities that are likely to have transformative outcomes.

1. **Acknowledge that science is social:** Members of the STEM community will be motivated by different logics, and it bears acknowledgement that social justice in science is both a moral imperative responsive to histories of exclusion, and crucial to the quality of the work (see, for example, Scott Page's analysis of the power of diversity for team performance). In a time that team-based science and large collaborations increasingly predominate as a mode of scientific inquiry and work, investments in the social dimensions of the scientific enterprise are investments in its productivity and creativity.

2. **Raise the bar for evaluation:** We observed two common weaknesses in the papers and program evaluations that we read of interventions: depth of engagement with the current state of social science and educational theory, and creative use of evidence to describe whether and how changes were occurring. We recommend that within calls for proposals, that the Sloan Foundation and others explicitly request that grantees articulate theory of how their investments will facilitate desired changes, and the use of multiple types of evidence to track such change.

3. **Take an intersectional equity perspective:** Scholars such as Estela Bensimon and Alicia Dowd (2015) have called attention to the risks of a diversity and inclusion agenda for reducing inequities. "The particular discourse that is used in instituted diversity programs matters, because commodified and color-blind 'inclusiveness' dissipates the initial thrust of the diversity agenda as a matter of civil rights" (p. 59). The Biden administration, through an executive order on his first day in office, has similarly urged national attention to racial equity in our collective effort to manage the continuing salience of the color line. Equity can be defined as "reconfiguring structures, cultures, and systems to reduce disparities and empower marginalized groups" (Posselt, 2020, p. 2). We are likely to see more transformative outcomes to the extent that Sloan attends to both dimensions of equity -- representation that is captured in disparities and cultural dynamics that affect who is empowered or marginalized -- via awards that actively reconfigure the system of graduate education, These will, of course, take time and the time scale of awards should be kept in mind as new proposals are being funded. In this, the importance of taking an intersectional perspective was made clear to us in the literature review. Sloan could support investigation into how women of color from different racial/ethnic groups vary in their experience of particular interventions, for example, as a matter of equity and of inclusiveness.

4. **Strengthen systemic change efforts through equity checks:** Finally, in support of developing and evaluating the efficacy of equity-advancing systemic change efforts, Sloan and prospective grantees should be asking several questions. Table 2 lists three broad types of questions that can elicit either reflection on the part of project leaders and/or evaluation criteria on the part of the Foundation.

Table 2: Equity Checks For Systemic Change Efforts

How are leaders contending with damaging narratives?	Are resources in place for the desired changes?	How might this systemic effort contribute to a broader change agenda?
What does this effort do to counter stigmatizing beliefs in the community?	Is this effort scoped appropriately for the change that it is theorizing?	How well-articulated is the systemic nature of change that this effort is pursuing?
How do deficit-based or asset-based narratives about people and institution types manifest in programming? Leadership? Budgets?	Does this effort have the requisite perspectives and expertise on the team? What is the composition and record of its leadership?	To what extent are the cultures of a discipline, department, other organization likely to be affected? How do we know?
In what ways is this effort actively engaging with racism? In what ways is the team prepared to engage with race in both project activities and its operation?	What mechanisms for continuous learning for participants and leaders of this effort? Who is involved in them?	With what other efforts already underway should this effort be connected? What synergies or other benefits would connection make possible?

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