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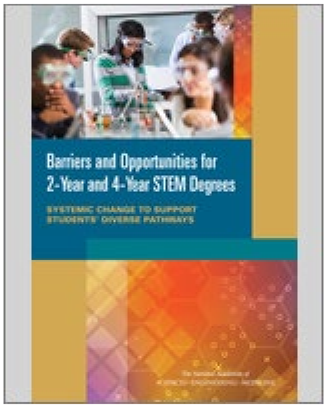

Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Students' Diverse Pathways.

The Culture of Undergraduate STEM Education

Major Messages

- The culture of science, technology, engineering, and mathematics (STEM) education has an effect on many students' interest, self-concept, sense of connectedness, and persistence in these disciplines.
- New research is needed to understand whether STEM "gateway" courses continue to negatively impact STEM student persistence due to the culture of the classrooms and a heavy reliance on lectures, as research from over a decade ago has revealed.

The complex array of pathways that students take to STEM degrees is not easily navigated, and students sometimes encounter barriers along the path to earning a degree. The environments they encounter when they begin college may not be welcoming, and the teaching may be uninspired. Barriers also result from departmental, institutional, and national policies. They may find themselves inadequately prepared for the rigor of college coursework or they may face stereotypes from faculty or peers. Students may encounter these barriers in classrooms and in other aspects of campus life. In this chapter, we address the barriers that students encounter related to the culture of STEM education: that is, the shared patterns of norms, behaviors, and values of STEM disciplines that manifest themselves in the way courses are taught and the classroom is experienced. We explore barriers related to instructional quality and policy barriers in the following chapters. By "culture," we mean the explicit and implicit customs and behaviors, norms, and values that are normative within STEM education (National Research

Council, 2009). It is important to focus on the culture of STEM education because the social, psychological, and structural dimensions of STEM education in colleges and universities influence how students connect their personal identities to their academic domains and view themselves as learners in those domains (their academic identities), which subsequently affects their efforts and achievement (Cabrera et al., 1999; Eccles et al., 1998; Reid and Radhakrishnan, 2003; Perez et al., 2014). The academic climate that individual students experience in college—their perceptions of interpersonal interactions and norms—is a manifestation of the college culture and one factor that influences student performance, engagement, and persistence outside of what would be predicted by socioeconomic or academic preparation indicators (Chang et al., 2011).

The importance of culture cuts across all institution types and pathways to STEM credentials. College campuses and the STEM departments and programs in them represent distinct types of organizational settings, with cultures created and perpetuated by physical structures, policies, underlying values, and social norms that guide their functioning. The cultures that students experience shape their awareness and understanding of standards, expectations, and their belonging. For example, the small numbers and limited examples of black professionals in such fields as geosciences might lead to perceptions by those in the field that reinforce the belief that "black people don't do geology." Similarly, in traditionally male-dominated professions, such as engineering, women may need to overcome explicit and subtle cultural messages that men are better suited for such professions (Cech and Waidzunas, 2011). The cultures that male and female students from all backgrounds, races, and ethnicities encounter while they study STEM can undermine or support their performance and persistence through their self-concepts and beliefs specific to the STEM domain and their feelings of community and belonging in STEM fields. In this chapter we focus on how the culture of STEM education impacts women and underrepresented students because of the concerns about participation of students from these groups in STEM fields and because students from these groups are typically the subject of research on the effect of the culture of STEM education.

The relationship between institutional or disciplinary culture and race, ethnicity, and gender is especially relevant in STEM fields, where racial and ethnic minorities and women are even more underrepresented than they are in most other fields (Anderson et al., 2006; National Research Council, 2011). For historically underrepresented students, views of the way race, ethnicity, and gender function in their college environment are especially important in their social and academic adjustment (Reid and Radhakrishnan, 2003). Experiencing a college culture with a hostile or unwelcoming racial environment has been related to social and academic withdrawal (Cabrera et al., 1999; Hurtado et al., 1998; Yosso et al., 2009), academic and social isolation (Allen, 1988; Fleming, 1984; Nettles, 1988; Ali and Kohun, 2006; Strayhorn, 2010a, 2012), and a host of other negative consequences (see below). In situations where students are underrepresented—as the only woman or Hispanic person in a class or department, for example—their social identities are more salient to both minority and majority group members (Hurtado et al., 1996). The value of cultivating diversity in science is described in Box 3-1.

WAYS OF KNOWING AND DISCOURSE IN STEM EDUCATION

As described in a previous National Research Council (2009) study, conceiving of culture as shared repertoires of practices sometimes leads researchers to refer to membership in almost any type of group as membership in a culture. This conceptualization of culture is highly relevant to undergraduate STEM education, which prepares students to become members of a group: professional scientists, technologists, engineers, or mathematicians. Thus, STEM learning can be viewed as a cultural process in which the practices and assumptions of STEM education reflect the culture, cultural practices, and cultural values of STEM professionals (National Research Council, 2009). From this perspective it is not surprising to find that a STEM educator's notion of what counts as scientific reasoning and sense-making practices reflects those that are valued and used by STEM professionals (Ballenger, 1997).

An educator's notion of what counts as scientific reasoning and sense-making can become a barrier for some STEM aspirants. For example, the discursive norms in STEM classrooms around debate and argumentation with student peers and instructors may not reflect students' own prior experiences and norms in their communities and schools (Brown, 2004; Kurth et al., 2002). An example is the idea of argumentation with an elder, which is not seen as acceptable behavior in some communities. Similarly, researchers have characterized the language of STEM as reflecting white, middle-class, masculine norms, which may be at odds with norms of expression more likely found among women and students from historically underrepresented groups (Brandt, 2008; Lemke, 2001; Olitsky, 2006); this disconnect can prevent them from identifying with STEM (Carleone and Johnson, 2007; Olitsky, 2006; Ong, 2005).

In other cases, students must first recognize and then negotiate and reconcile differences between their culturally based epistemological beliefs and those of mainstream science contexts, which may be invisible to instructors or be perceived as resistance or disengagement (Nelson-Barber and Estrin, 1995). This barrier is particularly salient for Native Americans and Alaska Natives, whose ways of knowing and views of the natural world often diverge from those present in STEM classrooms (Aikenhead, 1998; Bang et. al., 2007; Cobern and Aikenhead, 1998). Native American and Alaska Native students may be marginalized by STEM instruction that portrays scientific ways of knowing as free from value and above the influence of context, because such instruction is at odds with their cultural self-identity (Aikenhead and Ogawa, 2007). In fact, Aikenhead (2001) argues that only a small minority of students have world views and self-identities that align with the ways of knowing frequently conveyed in STEM classrooms.

A barrier that many students experience within the normative culture of STEM includes the view that inherent or natural ability determines a person's capacity for STEM learning, more so than other subject domains (Crisp et al., 2009; Dai and Cromley, 2014; Smith et al., 2013). A belief that natural ability determines capacity for STEM may vary by field. Recent research has shown that the extent to which professionals in STEM fields believe that innate talent is required for success is a strong predictor of representation of women and blacks in that field (Leslie et al., 2015). Fields where professionals believe innate talent is necessary tend to have fewer women and minorities. The overall message conveyed is that success in STEM fields requires either natural ability in mathematics or science or very early exposures to high-quality training. Related to this view is the tendency for introductory mathematics and science courses to function as gatekeeper courses that discourage students from continuing to pursue a STEM degree: see Box 3-2 for a detailed discussion of mathematics. Although practices and structures may vary across institutions and STEM departments, there are concerns that STEM gateway courses are characterized by a culture of highly competitive classrooms that do not promote active participation. The implied goal of these courses is to distinguish between those believed to have the ability to succeed in STEM from those who do not and “select out” the latter (Crisp et al., 2009; President's Council of Advisors on Science and Technology, 2012). In such settings, students from historically underrepresented backgrounds may be particularly likely to experience low expectations exacerbated by bias and small numbers of students from their group (their token status) in the field. Empirical support for these concerns is limited to a small number of studies with a limited sample and data from the mid-1990s (Gainen, 1995; Seymour and Hewitt, 1997). Additional studies of the nature of instructional strategies and the classroom culture are needed to determine if the continued criticism of these courses is warranted.

BELIEFS ABOUT ABILITY TO LEARN STEM

Increasingly, studies of college students have linked students' beliefs about their academic ability in STEM to their STEM performance and persistence (Carleone and Johnson, 2007; Chemers et al., 2011; Perez et al., 2014; Williams and George-Jackson, 2014). Emerging research illustrates how negative ability cues and stereotypes in college can be overcome.

Ability cues (signals of what ability is, who has it, and who does not) are commonly conveyed in academic settings and are embedded in their structures and practices. These cues can influence students' views of their own ability. Research on implicit beliefs about ability show that students who think of ability as fixed respond to academic settings in different ways than those who think of ability as malleable (see, e.g., Dweck and Leggett, 1988). Students with fixed beliefs about ability are more likely to avoid challenging tasks and to view challenge as more threatening to their self-concepts. They are more likely to respond to challenge or failure by feeling helpless, avoiding help-seeking, and ultimately, disengaging. In contrast, students who view ability as malleable view failures as opportunities to learn, are persistent in the context of challenge or failure, and are more likely to seek help (Dweck, 2000). Thus, believing that ability in STEM can improve with learning and effort is related to positive motivational responses and performance outcomes (Dai and Cromley, 2014). In fact, Dai and Cromley (2014) have shown that increases in fixed beliefs following entry into STEM courses predicted dropout in biology, beyond a student's grade. The increases in fixed beliefs were found to be associated with messages conveyed in gateway courses. The authors argue that the structure of the curriculum and instructional strategies are associated with changes in students' mindsets, thus, leading to engagement (with decreases in fixed beliefs) or disengagement (with increases in fixed beliefs).

Multiple studies have shown significant positive effects of interventions that target students' beliefs about their ability to succeed in STEM by suggesting that the causes of low grades are unstable (i.e., related to effort rather than ability) (reviewed in Snipes et al., 2012). For example, in an intervention developed by Wilson and Linville (1985), some struggling first-year college students were shown videos of college seniors discussing how their grades were low in their first year but had improved over time through hard work (Snipes et al., 2012). There is evidence from a number of studies that students who were randomly assigned to such interventions do better on both short-term and long-term performance measures. While there are a number of promising interventions and tools, there are questions regarding how to take the interventions and tools to scale. In particular, more research is needed to flesh out the interactions among target populations, educational contexts, and instructional strategies (Snipes et al., 2012).

Negative race and gender stereotypes about ability are particularly salient in STEM fields and may convey signals around the inherent or fixed nature of ability. For instance, research has noted the "undervaluing" of females and minorities in STEM, with lower expectation of their presence among geniuses (Hyde and Mertz, 2009). Thus, in STEM fields, underrepresented minorities and women may be particularly vulnerable to disengagement (leaving a STEM field of study) due to beliefs about their ability to succeed in STEM, even when accounting for prior academic preparation (Litzler et al., 2014).

These common stereotypes can be overcome, however. In one study (Aronson et al., 2002), students who received explicit messages in classroom settings around the incremental nature of ability (that it can improve over time with instruction and practice) at the beginning of their academic term showed greater academic enjoyment and engagement and higher performance at term's end than did students who did not receive such instruction. The positive relationship between messages and students' outcomes was observed for all students in the study with the strongest effects among black students. Thus, academic climates that emphasize learning, mastery, and improvement in math and science, rather than inherent ability, can promote both performance and persistence in those subjects through positive effects on students' self-beliefs. This effect may be especially strong for historically underrepresented groups, for whom negative academic stereotypes may be present in both subtle and overt ways in their day-to-day academic lives.

COMMUNITY BELONGING AND STEM EDUCATION

In addition to self-beliefs, students' connections to their campus communities can enhance their academic engagement and, subsequently, students' identification with their discipline, including their positive affect (feelings) toward the discipline (Fleming, 1984; Good, 2012; Hurtado et al., 2008; Johnson, 2011, 2012; Ko et al., 2014; Locks et al., 2008; London et al., 2014; Palmer et al., 2011). Connection to community covers both a sense of belonging to an academic setting (an institution, a department, or subgroups within them) and a psychological sense of community (a broader connection to the discipline or field area).

One study of an introductory electrical engineering class at a major university in the Northwest (Lee et al., 2006) found that positive affect and positive relationships with others were correlated with positive classroom experiences. The study also found that students with positive classroom experiences had a more positive career outlook. In contrast, students who do not experience a sense of community or belonging in STEM fields are more likely to leave STEM majors (Smith et al., 2013). Women report that "isolation" is a primary reason for their choice to leave science, technology, and engineering (Brainard and Carlin, 1998; Hewlett et al., 2008). Also, women's ambivalence about their belonging in computer science has been linked to their low level of participation in the field (Cheryan et al., 2009; Wolcott, 2001).

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RACIAL AND GENDER STEREOTYPES AND BIASES IN STEM EDUCATION

A host of psychological and educational research studies provides clear evidence that stigmatizing experiences—in the form of interpersonal discrimination—are a common occurrence for many racial and ethnic minority students, especially those in predominantly white college and university settings (see, e.g., Chang et al., 2011). This also occurs for women in STEM fields in which they are underrepresented (Brainard and Carlin, 1998; Hughes, 2012; Ramsey et al., 2013; Reyes, 2011). These experiences are a source of educational inequity as they negatively affect the quality of many of these students' social and academic experiences (Chang et al., 2011). These negative experiences can lead to a decreased sense of connectedness and community within students' academic settings.

When individuals perceive that negative stereotypes about their group are salient in a particular situation or context, they experience "stereotype threat" (Steele, 1997). The "threat" is represented by individuals' apprehension that they may be viewed in ways that are consistent with group stereotypes. Numerous studies have demonstrated that stereotype threat negatively affects performance on academic tasks (e.g., Aronson and Salinas, 1997; Gonzales et al., 2002; McKay et al., 2002; Schmader and Johns, 2003; Steele and Aronson, 1995). Under repeated stereotype threat conditions (i.e., typical day-to-day academic contexts in which stereotypes are often salient), students may respond by psychologically disconnecting their personal identity from the academic domain (academic dis-identification). In doing so, students may come to minimize attributes and behaviors necessary for success in their educational domain and develop personal identities in areas outside of that domain (Cokley, 2000; Crocker and Major, 1989; Osborne, 1997, 1999; Steele, 1997). Although this coping response may help protect students' self-concept, it undermines the motivation and engagement necessary for positive performance and persistence in an academic domain. For instance, it is possible that repeated exposure to stereotype threat in STEM courses among underrepresented students who intend to earn a STEM degree leads these students to "dis-identify" with STEM while at the same time retaining their connections to education and college more generally. In doing so, they still may be successful in attaining a college degree in another major area, but they would be less likely to attain STEM degrees or aspire to pursue STEM graduate degrees or careers.

In addition to indirect messages about ability and belonging embedded in academic cultures in higher education, there is evidence that underrepresented students—relative to their majority peers—commonly encounter more overt stigma experiences. Those experiences have been characterized as microaggressions, from instructors, peers, administrative staff, and other staff. These microaggressions are subtle or overt statements and behaviors that intentionally or unintentionally communicate devaluing messages about a group, including expressed low expectations (e.g., Fries-Britt and Griffin, 2007; Hurtado et al., 2011; Nadal et al., 2014; Solorzano et al., 2000; Yosso et al., 2009). Experiences of microaggressions can lead to feelings of invisibility: students feel as if they are viewed only in terms of stereotypes rather than in terms of their unique identities and characteristics (Franklin and Boyd-Franklin, 2000). For example, in one study (Smith et al., 2011), black male students who experienced stereotype-based treatment in their daily college contexts (e.g., being treated as intellectually inferior or as criminally deviant) were more likely to have feelings of isolation on campus that inhibited their academic performance.

An equally insidious phenomenon is the "benign racism" or "benign sexism" that can occur in mentoring, referred to as the "mentor's dilemma" (Cohen et al., 1999). This dilemma refers to faculty who are mentoring students across "cultural lines." In such cases, faculty members are less likely to provide tough, specific feedback to minority students due to concerns about appearing biased. Instead, faculty members may overpraise performance or effort and provide vague feedback in attempts to affirm students and convey a supportive environment or to "protect" students' self-esteem. Often these actions reflect faculty's implicit biases, based in negative cultural stereotypes about ability. Consequently, underrepresented students do not access and benefit from the same high-quality feedback as do other students. In both cases, students' experiences signal perceptions of their low ability in ways that can undermine their self-concept and subsequent engagement. Unfortunately, these experiences can serve to undermine students' own views of their ability and make them feel less valued, and subsequently, less connected to their academic settings. The experiences of female students from underrepresented minority groups are discussed in Box 3-3.

Changes to departmental or institutional culture can make a difference. A recent study (Ramsey et al., 2013) compared women in STEM departments characterized by welcoming versus traditional (unwelcoming) cultures for women. The welcoming cultures were characterized by more positive, visible messages about women in STEM, more women identifying in STEM in visible ways (carrying or wearing markers of STEM majors), and more peer role models. The women in the welcoming climate had fewer concerns about whether they would succeed and increased STEM identification. This research demonstrated the potential for institutions to create (and re-create) STEM contexts in ways that enhance inclusion and participation for historically underrepresented groups.

CULTURAL STRENGTHS AND ASSETS OF STEM STUDENTS

Despite the risks and challenges faced by many minority students, significant numbers of STEM students from traditionally underrepresented groups show positive adjustment and are academically successful. There are a handful of systematic studies examining this within-group variation: How do personal, cultural, and contextual factors contribute to positive academic adjustment and to persistence in STEM fields of study? Several factors that may supersede or buffer the negative effects of stigmatizing contexts for many minority students have been identified (Chang et al., 2011), including parental support, intellectual development, and social connectedness to others, as well as students' awareness of and development of coping skills around experiences of racism and discrimination. Ko and colleagues (2014) illustrate that women's efforts to draw on personal, peer, and cultural supports are critical to maintaining their interest in science and their psychological well-being in contexts that devalue them. Women that persist in science often take extra strategic steps to get the mentoring and training they need when it is not provided in their academic settings (Ko et al., 2014). This study suggests that women and underrepresented students who persist in STEM may do so not necessarily because of changes or improvements in the STEM culture at their institution. Rather, they persist because of their agency and developed personal and cultural resources. Some of the co-curricular supports have been developed to support students' agency and personal and cultural resources (as discussed in Chapter 4).

Other studies have shown the need to acknowledge the strengths and positive educational values associated with minority students' cultural identities that are all too often ignored in favor of stereotypical views of minority groups as resisting and devaluing education (Hope et al., 2013; Ko et al., 2014; Yosso, 2005). For instance, scholars describe how black and Hispanic college students who experienced subtle and overt racism in their academic contexts actively pursued academic and professional excellence to "prove wrong" racialized and gendered assumptions and low expectations based in stereotypes (see, e.g., Fries-Britt and Griffin, 2007; Yosso et al., 2000, 2009).

Similarly, McGee and Martin (2011) examined the process of "stereotype management" among a sample of black college students in mathematics and engineering to explain their achievement and persistence. The students' moved from awareness that their racial identities were under valued and feeling they needed to prove stereotypes wrong to their emphasizing the strengths associated with their racial and cultural identities, and to adopting more self-defined reasons to achieve. While this study found a connection between stereotype management and success in mathematics and engineering, students maintained a constant state of awareness that faculty and other students viewed black students as inferior in mathematics and engineering contexts. For example, as expressed in statements, such as "Really? Wow! I didn't think you would be able to answer a question like that! And no one helped you? (comment from an engineering professor directed to an African American female participant) (McGee and Martin, 2011, p. 2). In addition, the presence of stereotypes can be apparent to STEM students even when they are not expressed verbally or through nonverbal cues (McGee and Martin, 2011). As one student in the study explained, "even when no one uttered a word to him or gave him a 'What are you doing here?' glance, he still felt overwhelmed by the presence of that stereotype in most of his mathematics classrooms" (McGee and Martin, 2011, p. 18).

These lines of research challenge prevalent stereotypes and deficit perspectives of minority students as less able or less identified with academic pursuits. In addition, this research acknowledges student agency and avoids framing these students as passive victims of the types of unsupportive cultures and stigmatizing experiences they may face.

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SUMMARY

The culture that students encounter when studying STEM has an effect on their interest, self-concept, sense of connectedness, and persistence in STEM. Many students encounter messages that success in STEM fields requires either natural ability in math or science or very early exposures to high-quality training, which tends to be associated with lower persistence among women and minorities. Academic cultures characterized by race, ethnic, or gender stigma may lead students to assess those academic contexts as incompatible with their personal identities;

they may thus dis-identify with or disconnect important aspects of their personal identity (e.g., self-esteem, self-concept, personal values) from the academic domain (Steele, 1992; Steele et al., 1998).

Students who persist often have to draw on personal, cultural, and co-curricular resources to counter messages about the nature of ability and stereotypes that they encounter in interactions with faculty and are embedded in organizational norms and practices. At the same time, institutions have the potential to create STEM academic climates that promote engagement, sense of connectedness, and persistence among students by positioning STEM as a context in which one can learn and develop, avoiding emphasis on inherent or natural ability. Institutions can also improve the academic climate by addressing the subtle and direct ways that students may experience messages and treatment in STEM contexts that are based on negative racial and gender stereotypes, including acknowledging and drawing on the cultural strengths that underrepresented students bring to their academic contexts and in efforts to develop or improve curricular and co-curricular practices and programs. These issues and others are discussed in detail in the following chapter.

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