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Culturally Relevant Pedagogy: A Model To Guide Cultural Transformation in STEM Departments

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Despite recent interest and pressing need, we lack a clear model of culturally relevant, responsive, sensitive teaching in university STEM departments. Most culturally relevant efforts within STEM education address actions individual professors can take within their own classrooms and mentoring, rather than describing how to go about enacting cultural transformation at the departmental level. In this article, we propose the application of the Ladson-Billings model of culturally relevant pedagogy to promote an inclusive culture within undergraduate STEM departments. The model consists of three components: academic success, cultural competence and integrity, and critical consciousness. We define each component and describe what it looks like and how it can be used to guide departmental transformation, including examples in biology, physics, mathematics, and computer science departments at our own institution. This model can help guide faculty committed to creating departments where all kinds of STEM students can thrive, provided they are willing to work hard.

INTRODUCTION

University science and math departments are in need of widespread cultural transformation. By cultural transformation, we mean becoming departments where all kinds of students feel that they belong and where, with sufficient effort, all kinds of students can be successful, regardless of race or ethnicity, gender, socioeconomic status, first-generation college status, physical ableness, or other underserved group within the STEM community. As is, departments are losing talented students due to factors unrelated to their talent. Biology in particular has strong initial interest from women and students of color (1), yet these individuals are lost at various points within their education (1–3). We focus on belonging because belonging and academic success are linked; students' sense of belonging in their STEM department predicts student persistence better than scientific self-efficacy (4). Researchers have found that white men have the highest sense of belonging in STEM, and women of color the lowest (3, 5). Students who leave STEM majors (including both men and women, and all racial groups) reported a lower sense of belonging in STEM than those who persist (5). Students from underrepresented groups (black, Latinx and American Indian students; women of all races) are less likely to feel they belong, and women of color, including those who have persisted, reported the lowest levels of belonging of any group. Further, women feel a weaker sense of belonging in STEM when they believe that STEM faculty show gender bias (6).

Other work in STEM education has focused on departmental transformation as a key lever for widespread change within the field (4, 7–9). However, little is known about how to bring about this transformation. Most culturally relevant efforts within STEM education address actions individual professors can take within their own classrooms and mentoring. This includes: bringing culturally relevant examples into specific classrooms (10–13), being aware of stereotype threat (14, 15) and implicit bias (16, 17), and improving individual mentoring and research experiences (18–20). While these strategies are important, they are not sufficient to create a sustained cultural shift at the departmental level.

We wrote this article for university scientists and mathematicians who want to transform the culture in their departments so that all kinds of students feel they belong. We refer to this process as inclusive transformation. Our purpose is to offer a conceptual model to guide this process. Our model is based on a framework for culturally relevant pedagogy developed by Gloria Ladson-Billings (21–23). Her model consists of three main components: academic success, cultural competence, and critical consciousness. In this article, we tailor her framework so that it can be

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used to guide inclusive transformations of science and math departments. The resulting model is simple, flexible, and comprehensive and points to concrete actions professors can take at their own institutions.

LITERATURE REVIEW

Ladson-Billings' model of culturally relevant pedagogy was developed to describe effective elementary school teachers, but we will show that it also works well to describe an inclusive university science or math department. This model has been implemented across settings and age groups (24–26). In a synthesis of research since 1995, Aronson and Laughter found that the use of culturally relevant pedagogy was correlated with increases in student motivation, interest, "ability to engage in content area discourses," "perception of themselves as capable students," and higher test scores (27). The focus of culturally relevant pedagogy is not on helping individual students succeed but on the common good; it is "specifically committed to collective, not merely individual, empowerment" (21). The model has three central components: "(a) students must experience academic success; (b) students must develop and/or maintain cultural competence; and (c) students must develop a critical consciousness through which they challenge the status quo of the current social order" (21). We believe that science and math departments committed to inclusive transformation can use these components to judge their current practices and develop new practices. In this section, we develop each component in the context of research on the challenges to creating more inclusive science and math departments as well as previous research on effective inclusion strategies.

Academic success

The first component of the model is a robust focus on students' academic success. Academic success means more than just providing opportunities for students to learn science and math; it means ensuring that those opportunities are open to all kinds of students, including students who had the misfortune of attending high schools with inadequate math and science curricula. In the United States, we have what amounts to two K–12 school systems: one attended mostly by white affluent students, the other attended by a mix of black, Latinx, and white students, mostly lower income. Of course there are some predominantly non-white schools that offer superb educational opportunities, but by and large predominantly white schools receive more per-student funding (28, 29), have more experienced and effective teachers (30), teach fewer students who qualify for free or reduced meals (31), and are more likely to offer a full range of high school math and science courses (32).

These differences in opportunity lead to predictable differences in academic opportunity and outcome. White students are more likely to be placed in gifted education (even after controlling for test scores) (32, 33), take and pass AP classes (32), graduate from high school (34), and attend and graduate from college (35). White students are less likely to be suspended even after controlling for infraction (36, 37). To transform science and math departments, professors must take these inequities into account. As Carter, Skiba, Arredondo, and Pollock remind us, "you can't fix what you don't look at" (38).

This situation can seem hopeless. How can university faculty make up for years of inadequate instruction? Research indicates that these inequities can be addressed by focusing on students' strengths while providing opportunities to make up for what they were not offered. This necessitates a delicate balance. Viewing students as deficient can negatively impact learning (39). However, recognizing that some students arrived at college with weaker backgrounds is not the same as viewing them through a deficit lens. A way to strike this balance is to redefine what it means to be "a promising student": liking science, working hard, and asking good questions, rather than having strong exam scores right out of the starting gate. One technique that has been shown to support students with high interest but weaker preparation is to offer summer bridge programs to front load information (40, 41). Tanner has collected 21 teaching strategies that biology faculty can incorporate into their classes to give all students opportunities to talk and think about biology and to build a more inclusive, equitable classroom (42). This work is urgent: students' experiences in introductory science and math courses have a direct effect on whether they persist (3, 43–47).

Cultural competence

The next component of this model is to create a department culture in which students feel they can be themselves. Ladson-Billings calls this cultural competence, but this does not just mean being able to work with people from different cultural backgrounds; in this model, cultural competence means "helping students to recognize and honor their own cultural beliefs and practices while acquiring access to the wider culture" (48). In university science and math settings, this means departments that deliberately broaden norms and practices so that students from nondominant cultures feel welcomed. Tanner and Allen write about cultural competence similarly: "Perhaps one reason why efforts to diversify science have made little progress is that we've spent too much effort trying to inculcate diverse populations of students into the culture of science as opposed to changing the culture of science itself to be inclusive of them" (49).

Becoming more culturally competent might mean curricular changes that incorporate students' cultural knowledge, as in a chemistry classroom where students analyze traditional beliefs scientifically (50). However, professors can still create an environment where students feel they belong and can be themselves without making changes to course content. For example, actively encouraging the contributions

TABLE 1.
Culturally relevant pedagogy (21, 23).

Academic success	Creating conditions under which a wide variety of students, provided they work hard, actually achieve success.
Cultural competence	Creating classrooms and departments where students do not experience a conflict between their lives as science students and other parts of their identities.
Critical consciousness	Thinking critically about the culture of science.

of all students using classroom response systems (51) and small group work (52) increases learning of all students and promotes a sense of intellectual community (53). Assigning roles promotes equity in small groups (54, 55); more guidance on effective group work can be found in the relevant CBE Life Sci Educ Evidence-Based Teaching Guide at https://lse.ascb.org/evidence-based-teaching-guides/group-work/ (56). A study of noncontent instructor talk in an introductory biology course shows how instructors can also use language to create a welcoming classroom culture (57).

We believe that creating departments where students can feel culturally competent is going to require professors to take control of the department culture, rather than letting students set it. In typical college STEM settings, gender, race, and ethnicity have been shown to be strong predictors of student behavior. Researchers have found that in small groups, men preferred to take on roles as "leaders and explainers," women preferred being "collaborators" (a mix of explaining and listening), and non-white and international students preferred being "listeners" (55). Male students overestimated their own performance and underestimated that of their biology classmates, particularly female classmates (58). Similarly, male students and native English speakers had higher academic self-concepts than female students and non-native English speakers with a physiology classroom, and students' self-concept affected how much they participated in small-group discussions (59). These findings suggest that a culturally transformed math or science department must actively push for inclusive norms if they want female students and students of color to participate as actively as their white, male, native English-speaking peers.

Supporting cultural competence in a transformed department might also include preparing students for other STEM settings: helping them understand STEM cultural norms and expectations, and ensuring they have the skills and knowledge to succeed. One way to do this is through strong, shared department mentoring practices; Braun et al. provide a framework to incorporate cultural capital within the mentoring relationship (60), while Aikens et al. focus on social capital (61). Haegar and Fresquez illustrate the gains that can be made when incorporating both social and cultural capital within the research mentoring relationship (62).

Critical consciousness

This model requires that professors think critically about culture and power; we will argue that this is key to transforming departments. This means being able to "critique the cultural norms, values, mores, and institutions that produce and maintain social inequities" (21). Aronson and Laughter add that critical consciousness "begins with teachers recognizing sociopolitical issues of race, class, and gender in themselves and understanding the causes before then incorporating these issues in their teaching" (27). It is particularly important that STEM professors have critical consciousness because so many are white men, and because of the elite status of STEM; scientists, engineers, mathematicians, and computer scientists occupy powerful positions in society.

Students who are underrepresented in STEM settings experience subtle biases, which have major effects on their entry into and persistence in the disciplines. Being critically conscious means taking these biases seriously. For example, there is a tight correlation between the belief that success in a field requires "a special aptitude that just can't be taught" and the number of women and African Americans holding U.S. PhDs in that field (63). Biology, chemistry, and physics professors have been shown to perceive males as more competent and deserving of higher salaries and more mentoring, even when controlling for gender, field, age, and tenure status of the professors (64). Harrison and Tanner discuss the damage caused by microaggressions in STEM settings (65); 15 of 17 black women and Latinas reported experiencing microaggressions while majoring in physics (66).

Without critical consciousness, professors may focus only on recruiting underrepresented students to their departments. Recruiting underrepresented students without trying to eliminate biases that they may face will not lead to departments where all kinds of students feel they belong. Professors who want to transform their departments must understand that typical cultural norms of science departments may benefit certain kinds of students (male, white and Asian, affluent) while disadvantaging others (female, black, Latinx, and American Indian, poor). Killpack and

Melón provide an excellent guide for faculty development on these issues (16).

In the rest of this paper, we further develop what these components might look like in university science and math departments. In the section "What this might look like in practice," we provide concrete examples. In the Discussion, we incorporate these examples into our model of a culturally relevant university STEM department.

METHODS

This article is not a report of a research study. Rather, it is the result of conversations between the authors about how science and math departments could engage in department-wide inclusive cultural transformation. Elliott is a biologist, Johnson is a teacher educator, and both of us engage in research and activism around equity in science education. Johnson realized that the effective practices we were discussing align tightly with Ladson-Billings' framework for culturally relevant pedagogy, and this insight led us to collaborate on this article, in the hopes that the framework would be useful to others who share our commitments. Although this is not a research report, it is grounded in systematic qualitative research and systematic program evaluations we have carried out over the past 15 years.

Data sources

Our evidence is drawn from data collected at our own institution, St. Mary's College of Maryland (SMCM). Our Math and Computer Science, Biology, Chemistry, and Physics departments all have robust habits of self-assessment, so we have access to various forms of data collected over the past 15 years. In addition, in 2015–2016, Johnson conducted interviews of faculty and students within the Physics department and the Math and Computer Science department. All research cited in this article followed approved Institutional Review Board protocols or was designated exempt programmatic analysis.

Data source 1: Physics, math, and computer science interviews. Data included participant observation, interviews, and focus groups (67–69). During the first 2 weeks of the fall semester of 2015, Johnson attended at least one class session in all 17 100- and 200-level physics, math, and computer science classes, as well as 7 300- and 400-level classes, to observe how cultural norms were established.

She interviewed 13 physics, math, and computer science faculty members (out of a total of 16), including all women faculty. Rather than recording interviews, Johnson took notes in real time and then sent transcripts back to participants to be amended to reflect their intentions. Most interviews lasted about an hour; questions included:

- What does it mean for someone to be a good physics, math, or computer science student?
- What do you do as an individual to support and teach students?
- What does your department do?
- Why do you think St. Mary's has good numbers for retaining women students in your department, and what could be done even better?
- Women faculty only: What was it like for you to study in this field?

She interviewed 17 women students (out of 58) from the three majors, with women of color oversampled (see Table 2). At least one of the women interviewed was trans. She asked all students just one question: "Tell me how you decided to major in [field] and what it's like," with subsequent prompts that followed the women's narratives. Interviews lasted for about 45–90 minutes and ranged widely after the initial question.

Johnson conducted three focus groups in large upper-level classes in each of the three disciplines. In each class, she asked the following questions:

- Why did you decide to major in [field]?
- What was your route to majoring in [field] at St. Mary's College?
- Was it the same as you thought it would be? How is it the same? Was it different? How?
- What is it like to major in [field]?
- What do you like about [field] classes?
- What could be even better?
- St. Mary's has higher rates of women in [field] than most other liberal arts colleges. Why do you think that might be?
- Do you have ideas about attracting even more women?

In each class she explained to students that the goal was to gather the widest range of responses possible and then to see how typical each answer was. After she posed a question, she asked students to keep offering responses until there were no more new answers; then she asked them to indicate, by raising their hands, how many of the responses they agreed with. Johnson also conducted a focus group at a tea put on by the members of the Women in Science House (WiSH), a community of women science majors. At the WiSH tea, Johnson asked women what their experiences were like majoring in science and math at St. Mary's College, and they took turns answering this question and talking among themselves for an hour and a half.

All data were analyzed by sorting through the data to identify recurrent topics, turning those topics into codes, and finding as many instances of each code as possible across field notes, interviews, and focus groups (68, 69). Coded data were analyzed by looking for common themes, as well as disconfirming examples. The analysis was carried out using NVivo. Note that this analysis does not permit us to make separate statements about each major, nor to disaggregate findings by race. The size of each racial subgroup was too small to allow for any kind of generalizability, and so many students in each major were double majoring or

TABLE 2.
Characteristics of women with declared majors in physics, math and computer science at St. Mary's College of Maryland in fall 2015; characteristics of interview sample.

Characteristic	Total no.	No. interviewed
Majoring in physics, math, or computer science	58	17
Majoring or minoring in computer science	24	7
Majoring or minoring in physics	9	6
Majoring or minoring in math	44	10
White	42	11
Latina	6	2
Black	4	3
Asian	4	1
Sophomores	7	2
Juniors	24	5
Seniors	25	10

minoring in other departments that they found it difficult to distinguish between experiences in physics, math, and computer science.

Data source 2: Existing programmatic documents and analyses, including analyses of the outcomes of SMCM math, computer science, and biology Emerging Scholars programs (ESPs); SMCM STEM Navigators program outcomes (S-STEM grant #1154315); Introductory Biology course redesign (Lumina Foundation grant); alumni surveys; and data from the SMCM Department of Institutional Research.

What this might look like in practice

Our goal in this section is to describe what the components of Ladson-Billings' model of culturally relevant pedagogy might look like in a university science or math department committed to inclusion. We draw our examples from what we have seen at SMCM; however, we are not trying to argue that these departments are exemplars of inclusion. Nevertheless, we believe that the examples we have collected will let faculty better understand what these components might look like in practice. Before we get to the three components, however, we present evidence that students experience a sense of belonging in these departments.

Inclusive sense of belonging

We have not systematically measured students' sense of belonging in these departments. However, dozens of statements collected by Johnson captured St. Mary's STEM students' strong feelings of community and belonging. During focus groups, a female math major said she liked "the community of it. When we have homework or exams, we all come together. We know the pain together," at which her classmates laughed and voiced agreement. (Note: Johnson's agreement with participants precludes identifying the race and gender of some students. Because there are so few students in each pool (see Table 2), the agreement was to identify them only by major and gender, to protect their confidentiality. Students whose race is also identified agreed to this beforehand.) A female computer science major says that the program is "a lot more collaborative, a bigger sense of community" than she had expected; "not just independent people programming stuff all the time." Seventeen other people in the focus group of about 25 agreed. A white woman, on what it is like to major in physics, said: "I like how friendly everyone is. I love working with people on stuff…. I like the general sense of community that there is in [the science building]." Collaboration rather than competition is also a common theme within the SMCM biology department. Professors note that students unfailingly help each other rather than sabotage their peers with incorrect information or incomplete notes, and that this ethos is supported by the faculty. One faculty member summed it up by noting, "Students are internally competitive [to do their best], but not [competitive] with each other."

Critical consciousness

One math professor illustrated critical consciousness: "Social interactions matter…. Social interactions impact academic performance. And when those social interactions are about isolation, racism, and sexism and everything else, they take it one direction—they affect academic performance in one direction." A physics professor made a similar point: "We're aware that there are constraints on people who aren't following the stereotypical model, and we're going to deal with those as a community rather than make you deal with those by yourself."

Note that professors do not have to have high levels of critical consciousness to undertake inclusive transformation. At our institution, professors became more critically conscious as a result of participating in transformation processes. Johnson collected two different stories about this process.

Origin story 1: The virtuous circle. The first story comes from the Math department, and Johnson collected several versions from different math professors. Over 15 years ago, the department declared their department to be a "No Criticism Zone," which Johnson was told repeatedly was key to building an inclusive culture. One professor explained the No Criticism Zone this way: "As a departmental faculty, we've decided that we will not say negative critical things about students where students can hear—not just the student in question, but any students. We don't want a student to go back and say 'well geez, if they're willing to say that about so and so, what are they saying about me?'"

Several faculty members reported that the No Criticism Zone led to profound transformations in the way the faculty viewed their students. "You internalize these things. When you gripe about students, a little bit of that—you internalize, and you think worse of students. When you avoid griping about students, you think better of them, just because you're not saying those things." These changes led to yet more inclusive transformations; the department fell into a virtuous circle. Another professor said "I really feel like that mentality in many ways is—maybe the biggest single factor in terms of our growth, just in terms of numbers—our popularity on campus. How many schools do you go to where people think the Math department is cool?" By changing how they talked about students, these faculty began to think differently about their students.

The department instituted more inclusive changes, which attracted more students, which allowed the department to petition successfully for more faculty lines; their success with a wider range of students allowed them to attract other equity-minded professors. Over the years they have transformed from a faculty of five, one of whom was willing to focus on equity and one who was committed to it, to a lively faculty of 10 mathematicians and 4 computer scientists, with universal support for equity-focused pedagogical practices. Now, as one math major put it, "math is like a family. If you show the slightest interest in it, all the professors are like 'let me show you how much fun math can be.'"

Origin story 2: Data conversion. In this story, about 10 years ago the department hired a new professor who was proficient in both physics and also in the then-emerging field of physics education research. Meanwhile, the entire campus was under pressure to institute some sort of assessment system, so the Physics department adopted the Force Concept Inventory (70–72). The new professor taught introductory physics using inclusive, research-based practices; the department chair taught the course using a traditional lecture format. The students in the class of the new professor learned more. This again led to a virtuous circle, with the department chair adopting more inclusive practices. Both of these professors were committed to broadening participation in physics, which made the department more attractive to women physicists when positions came open, and now a faculty that was previously entirely male is 60% female. This has also attracted women physics majors (including women of color); about 30% of the physics majors are women, which is well above the national average of 20%. More impressive, since 2012 there have always been at least two women of color among the eight or so women physics majors, which is far above the national average; 2% of all physics graduates for the past 15 years have been black women and Latinas (73).

The transformation process at St. Mary's started with faculty who were willing to question the status quo in their fields (which is what Ladson-Billings means by critical consciousness). But their initial levels of cultural critique did not have to be particularly deep; for many professors, their critical consciousness grew over time, as they adopted more inclusive policies and teaching approaches and saw how this led to more satisfying teaching experiences and broader participation in their majors. Professors began to take pride in creating departments where students could thrive and where inclusion was valued.

For example, one professor was initially resistant to the idea that a student's race or gender would have any impact on their experiences. She analyzed social situations through a lens of color and gender blindness and firmly insisted that outcomes were determined by merit alone. She was, however, willing to try out research-based teaching strategies, and that experience, along with a willingness to consider evidence about implicit bias and inequitable outcomes, has led to an extraordinary change in her view. She was particularly affected by a study documenting the discrimination and microaggressions experienced by women graduate students in physics and astronomy (the study was later published; see reference 74). She now takes on issues of social justice not only in her classes but campus-wide. In her classes, "I've started talking with my students about implicit bias. I need to figure out the best way to do it, but it's a small thing I can do to help reduce implicit bias."

This critical consciousness on the part of professors leads them to try to spark similar insights among their students. "Changing our own behavior, to me, is not good enough. Changing our own behavior makes the immediate experience for our students slightly more equitable. Changing our behavior and discussing that with students has at least the possibility of changing the world." As a concrete example of what this might look like, a male computer science professor takes on the misogynist culture of video games directly: "Every single time I've run [my course], we've had a discussion of gender and racial representation in video games…. There are not a lot of women who are forefront in games" [interjection from female colleague: "And if they are, they forgot their clothes."] "And I will have one or two guys who are completely oblivious to it—it never crossed their mind that this would be a problem, that this is something that could be solved, that needs to be tackled."

Academic success

Supporting academic success in inclusive science and math departments requires deliberately building structures that help students succeed. In this section, we present some examples of what that might look like, including redefining academic success, ensuring reasonable time to degree completion, and support structures

Redefining academic success. A key step in transforming a department is to adopt an inclusive definition of academic success: what it means to be a good student in one's discipline. This is particularly important given research about the prevalence of unconscious bias against women and black and Latinx people in science and math (6, 64, 75, 76).

Examples of inclusive definitions of good STEM we have collected include "works hard," "works with others," is "not afraid to get the wrong answer," is "able to explain." One professor said "I enjoy it when they're naturally interested, but that doesn't have to be the case. The fun thing is taking someone who has a fear, and who dislikes math, and at the end of the semester they say 'oh my God, this is amazing, I never thought I could do this!' That's a good student too."

Ensuring students can finish STEM majors in 4 years. When a department regards good STEM students as students who ask good questions, collaborate, and work hard, suddenly there is a wider pool of exciting students to teach. However, a major obstacle to completing a STEM major is the ability to graduate within 4 years, particularly for students who did not have the opportunity to take rigorous AP classes. In response to this situation, our colleagues in math designed a major that can be completed in 4 years even if students start in Calculus I. This let them recruit from both students who had not previously considered math as a major and students from less-well-resourced high schools. A professor told us that "sometimes we'll get students in Calc[ulus] who had maybe a weaker background, never thought they were particularly good at math, and at the Calculus I or II levels I can usually judge by the sort of questions they ask that have very deep answers that I can't even get into at the calculus I level, but I recognize is the right sort of question that an abstract thinker would ask. I've pulled students [aside]… I usually don't push the math major right away, I say they should take one more course. I find that happens a lot [in this department]. I also find that does not happen at a lot of schools. A lot of schools that have well-known, historically strong math departments get almost none of their majors out of their Calc[ulus] I classes, whereas we get a lot." The department has effectively leveled the playing field for students to complete a mathematics degree.

Direct support for academic success. Redefining good science students also creates an imperative to better scaffold learning, in order to support engaged, curious students with weaker high school preparation. Elliott and colleagues redesigned a first semester introductory biology curriculum in 2011 (with funding from the Lumina Foundation) to incorporate more small-group work dealing with real-life examples of course content. This resulted in greater than 70% of black and Latinx students passing the course in the 2 years after the redesign, compared to the two previous years which averaged a 54% pass rate. All students in the course performed better after the redesign, with an overall 86% pass rate for students in 2011, with previous pass rates averaging 73%. This has been done at other locations with similar successes (77–79). By breaking from the traditional Socratic lecture model, the department was able to encourage and support a wider range of students in their studies.

Another element that supports widespread academic success is to offer enrichment opportunities for students outside of class time. At St. Mary's College, we do this using the ESP model. Emerging Scholars started at Berkeley as a way to improve the calculus performance of students from groups who are underrepresented in math; the model has been adapted at many institutions (80–84). ESPs focus on social integration of students and also on having students work in groups to solve problems that are harder than those they will encounter in their classes. We have offered ESPs in math, computer science, biology, chemistry and physics. Our ESPs are open to all students, but those from underrepresented groups (black and Latinx students; Pell-eligible students; women students) are strongly encouraged to participate. Black and Latinx participants in our computer science ESP have higher grades and are more likely to continue to higher computer science classes (85). In biology, professors have noted that ESP helps break down perceived barriers between faculty and students; ESP students are more willing to approach faculty outside of class and attend office hours. The ESP cohorts often work together long after the introductory class is finished. Implementing ESP at SMCM took relatively few resources compared to the gains in student retention: $25 per student per semester for refreshments, and the time of a faculty member (or two) to staff a 2-hour weekly seminar (0.5 total teaching credits for a semester, the equivalent of a laboratory section).

Culture of support for all students. A supportive environment can start at the level of the physical environment. At our institution, students work together in pleasant, flexible public spaces. The norm in these spaces is for upper-level students to welcome questions from students they do not know. An upper-level math major remembers that when she was in Calculus, "people were all really supportive, all the majors and minors were willing to help." Professors with open doors are willing to answer questions about any class, not just the classes they are currently teaching. A student-driven initiative matches junior Biology majors with first-year Biology students, which supports the first-year students in acclimating to departmental expectations. The next year, the sophomores then support their "big brother/ sister" during their senior thesis.

Cultural norms about working closely together can also break down isolation. When asked if she ever thought about being outnumbered in physics, a woman physics major said "now I've made friends with everybody and know everybody, I'm fine with it. But at first it's intimidating…. It gets tiring to be in an environment where people keep looking at you repeatedly. Like you're different or kind of like you're a sexual object. So I understand why people don't want to come into majors that are so male-dominated. [But now] it's not just a bunch of men—they're people you know, who you become friends with. So it's not like intimidating anymore."

We have seen that students embrace this push to collaborate. Another woman majoring in physics said of the physics majors "If we're in the same classes we do work together, if we're in different classes we try to help each other." A math major reported that "people don't realize that math is a really social major. When you think of math, you think of going off in a corner and doing your work. But if you come here at night, [the science building] is so busy. I knew that if I pursued the math major, I would have the necessary support. Teachers would care, and I would have peers that are in the same boat as me."

Cultural competence

Cultural competence means creating an environment in which students can feel they belong and can be themselves. This is crucial in STEM fields, which are haunted by the "lone genius" and "white men in lab coats" stereotypes. As one Physics professor put it: "The traditional methods that were problematic—'weed them out, produce someone that looks

TABLE 3.
A model to guide inclusive transformation in science and math departments.

Academic success
In inclusive departments, a wide variety of students, provided they work hard, achieve success. Professors in these departments…

- Recognize that STEM preparation is different from STEM aptitude and build pathways to success for students with weaker preparations
- Focus on students' strengths
- Use active learning strategies
- Use group work strategically (e.g., avoid isolating underrepresented students, give students specific roles to prevent some students from being marginalized, prove structures to monitor group work)
- Structure their departments so that students can demonstrate engagement and mastery in multiple ways

This might include:

- Redefining what promising science students look like
- Ensuring that science and math majors can graduate in 4 years
- Providing direct support for learning for all students, but especially for students without strong high school preparation
- Create a culture of collaboration among students

Cultural competence
In inclusive departments, students do not experience a conflict between doing well in science and other parts of their identities.
Professors in these departments...

- Establish an environment where a wide variety of students feel they belong and can be themselves
- Take control of the culture of their departments (to prevent the culture from being shaped by bias, intentional or not), but allow for student voice and buy-in

This might include:

- Combatting the stereotype of scientists as lone geniuses and white men in lab coats
- Emphasizing that success in science and math results from practice and collaboration

Critical consciousness
In inclusive departments, professors think critically about the culture of science.
This means that they…

- Recognize that typical cultural norms of science departments benefit certain kinds of students (male, white and Asian, affluent) while disadvantaging others (female, black, Latinx, and American Indian, poor)
- Actively work to reduce the impact of bias, inequity, and disadvantage
- Are committed to collective, not just individual, success and empowerment

This might include:

- Being willing to question the status quo in science
- Finding that levels of critical consciousness grow over time

like me, another physicist' approach to our goal is problematic if you're already starting with a bunch of white males as the professors. Also the whole idea of—'you've got to come in with some innate talent'—'the lone genius'—'let's revere Einstein and Feynmann'—that leads to people selecting people who look like them." Thus, if STEM faculty want to maintain an inclusive department, they need to make take on these stereotypes directly.

Faculty can combat the lone genius myth by indicating in word and deed that doing well in STEM entails practice rather than solitary innate talent. A math major told Johnson "I've had professors say in class 'this material is difficult,' it's ok that you're uncomfortable with it now, you're not supposed to get it right now, it takes a lot of time'—hearing them say things along those lines is very comforting…. Even if I wasn't understanding, it was OK and I wasn't necessarily in a bad place. That was something I definitely needed to hear because I didn't know that's how it should be." Without this framing, students who know they are not geniuses may feel they do not belong in STEM; in a previous study Johnson conducted of 24 women of color majoring in biology and other STEM fields, almost every one of them confided that she sometimes feared she was the only person struggling with the material (86). With this kind of private worry, students cannot possibly feel they truly belong in STEM; they cannot experience cultural competence. By contrast, a black woman whose professors downplayed natural ability and reached out energetically to her reported that "I felt supported, intelligent" in this warm and rigorous setting.

This approach also promotes growth mindsets, the idea that success comes from hard work, not innate ability (87). Prior research has established the link between growth mindset and performance and persistence in STEM majors, particularly for underrepresented students (88, 89). A professor explained how he and his department do this: "We explicitly mention it, we're emphasizing the discussion and exploring, making it safe to make mistakes—doing conceptual questions with clickers and having students talk about it—a low-stakes environment, they see that there are lots of other people who don't fully grasp it, and through working at it they collectively develop their understanding… focusing on collaborative working, and explicitly scaffolding and slowly removing the scaffolding." Notice how these approaches align with the inclusive definitions of academic success we discussed above.

DISCUSSION

A model for inclusive departmental transformation

In Table 3, we bring together everything we have discussed in this article. We summarize the obstacles to and effective strategies for building inclusive science and math departments that we discussed in our review of the literature. We also include examples of what each component of this model might look like in practice, drawn from our findings section.

Using this model to transform a science or math department involves teaching in ways that may be very different from the ways we as faculty originally learned our discipline. It also requires instructors to think about problems within the culture of science itself, a culture in which we, as academics, learned to succeed. This culture likely fits us well and predominantly perpetuates success of people like us. As one female math professor put it, "One of the factors that I see on the math end is that we try really hard not to have the competitive model of the major. My sense is that having a competitive model is one of the things that tends to make it less attractive to women. Mind you, this is another one of those things that I view as ironic because I was insanely competitive as an undergrad." Nonetheless, transforming our departments is the right thing to do if we are serious about supporting increasing diversity and equity within our fields. The material in STEM classes is challenging enough; creating department cultures centered on academic success, cultural competence, and critical consciousness is one way to keep the culture itself from adding an extra, pointless layer of challenge.

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