



TEACHERS COLLEGE, COLUMBIA UNIVERSITY

Improving Developmental and College-Level Mathematics: Prominent Reforms and the Need to Address Equity

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Abstract

In recent years, there has been a growing recognition that the traditional system of college mathematics remediation that relies on high-stakes placement tests and prerequisite, multi-level course sequences is associated with lowered chances of students completing developmental requirements and increased rates of student attrition. This recognition has led to nationwide reform efforts that strive to alter the structure and curricula of remedial math courses. However, these broad-based reforms have been insufficient in eliminating inequities in developmental placement and completion between students of color and other underserved students and their more advantaged peers. Informed by relevant research literature, this paper argues that the majority of reforms to developmental math education seek to remedy general barriers to student progress but are not typically designed to address equity gaps and, perhaps unsurprisingly, do little to reduce them. We examine issues of concern present in traditional developmental math education and how existing reforms—including assessment and placement reforms, acceleration reforms, contextualization reforms, and curricular and pedagogic reforms—aim to address these issues, noting if they are associated with reductions in equity gaps. Lastly, we explore the potential for targeted reforms in developmental math to more effectively address the factors that contribute to inequities in student outcomes, factors such as stereotype threat, math anxiety, instructor bias, and tracking.

About Launch Years

Launch Years is an initiative led by the Charles A. Dana Center at The University of Texas at Austin—in collaboration with Community College Research Center, Education Strategy Group, and the Association of Public and Land-grant Universities—focused on addressing systemic barriers that prevent students from succeeding in mathematics and progressing to postsecondary and career success. Leveraging work within states, the initiative seeks to modernize math in high school through relevant and rigorous math courses as well as policies and practices leading to more equitable outcomes for all students.

Learn more at: utdanacenter.org/launch-years.



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1. Introduction

When students arrive at college, they are traditionally assessed on their mathematics skills using a placement test. Based on the results, students may be placed in a college-level course or, if they fail to meet institutionally defined benchmarks of college readiness in mathematics, a noncredit developmental education course or sequence of courses designed to prepare them for college-level coursework.¹ In recent years, there has been a growing recognition that the traditional system of remediation that relies on high-stakes placement tests and prerequisite, multi-course sequences is associated with lowered chances of students completing developmental requirements and increased rates of student attrition (Bailey, Jeong, & Cho, 2010; Chen, 2016; Hodara, 2019). Because a college-level math course is often a requirement in programs of study, many students who fail to complete remedial courses do not continue on in their pursuit of postsecondary credentials.

Recognition of these general issues in developmental math education has informed nationwide reform efforts that strive to alter the structure and curricula of remedial courses in order to help the students who take them become college-ready more quickly and effectively (Fields & Parsad, 2012; Hodara, Jaggars, & Karp, 2012; Jaggars & Bickerstaff, 2018; Rutschow, Cormier, Dukes, & Cruz Zamora, 2019; Rutschow & Mayer, 2018; Rutschow & Schneider, 2011).² These reforms have begun to address several obstacles to student success, including: inaccurate and insufficient systems of assessment and placement, long multi-semester course sequences, and decontextualized math offerings and instruction that are not relevant to or well-aligned with students' fields of study (Rutschow, Cormier, et al., 2019).

While more students are taking college-level mathematics as a result of reforms to developmental education, racial/ethnic gaps in placement and outcomes persist (Hodara, 2019; Logue, Watanabe-Rose, & Douglas, 2016; Logue, Douglas, & Watanabe-Rose, 2019; Ran & Lin, 2019; Rutschow, Cormier, et al., 2019). The issues present in

¹ Students may earn credits for developmental courses, but the credits are not applicable toward a college credential.

² Much of the research on and reform to developmental education focuses on community colleges; that focus is reproduced in this paper.

developmental mathematics education disproportionately affect students of color and other underserved groups³ that have been historically underrepresented in higher education, because such students are more likely to be assigned to developmental courses, to be assigned at lower levels, and to have lower rates of completing these requirements and gaining access to college-level coursework (Attewell, Lavin, Domina, & Levey, 2006; Bailey et al., 2010; Chen, 2016; Hodara, 2019; Mejia, Rodriguez, & Johnson, 2019; National Academies of Science, Engineering, and Medicine, 2019). Broad-based reforms to developmental education have been insufficient in eliminating inequities in developmental placement and completion between students underserved in college and their more advantaged peers. In this paper, we argue that the majority of reforms to developmental math education seek to remedy general barriers to student progress but are not typically designed to address equity gaps and, perhaps unsurprisingly, do little to reduce them.

There are specific obstacles that underserved students face that contribute to inequitable rates of performance in college math. As a result of economic and racial neighborhood segregation, as well as under-resourced K-12 schools, underserved students are more likely to be deemed academically underprepared in math when they arrive at college (Entwisle & Alexander, 1992; Mickleson & Bottia, 2009; Mickelson, Bottia, & Lambert, 2013; Palardy, Rumberger, & Butler, 2015). Gaps in math performance begin as early as the second grade and compound over time through primary and secondary schooling and into postsecondary education, leading to racial/ethnic disparities in measures of mathematics college readiness (Balfanz & Byrnes, 2002; Entwisle & Alexander, 1992; Mickleson et al., 2013; National Assessment of Educational Progress, n.d.; National Education Association, 2015). The effects of these early disparities persist through college, when differential rates of placement into developmental math courses contribute to gaps in student progression and degree

³ While much of the literature reviewed for this paper focuses on obstacles facing Black students, some of it also focuses on obstacles facing Latinx, female, low-income, and first-generation students—students who often exhibit lower mathematics performance relative to White, male, and affluent students. We use the term “underserved” to refer generally to students from these populations that have been persistently underserved in mathematics higher education.

attainment (CUNY Taskforce on Developmental Education, 2016; Ngo & Velazquez, 2020).

Solutions that address only the obstacles common to all college students may be inadequate in reducing equity gaps (Toldson, 2018). An effective solution to inequitable college math outcomes should thus address the specific factors identified in research as contributing to inequity. These include stereotype threat, unaddressed math anxiety, implicit biases of teachers, and tracking. While this is not an exhaustive list of factors, interventions that focus on these issues are likely to improve the math outcomes of all students and may be particularly helpful for underserved groups. Postsecondary solutions that fail to address these factors are more likely to maintain existing inequities.

In section 2 of this paper, we describe the rationale for recent reforms to developmental math. In section 3, we discuss reforms aimed at improving general causes of low developmental math completion. We also discuss the extent to which these reforms, though not explicitly designed to do so, are associated with reductions in equity gaps. In section 4, we explore the potential for targeted reforms to more effectively address the factors that contribute to inequities in student outcomes. In doing so, we examine root causes of math equity gaps and identify factors frequently experienced by underserved students, which, if addressed, have the potential to contribute to a reduction in gaps. We conclude with recommendations in section 5.

2. The Need for Reforms to Developmental and College-Level Math Education

In this section, we explain three key issues that have motivated reforms to developmental math: inaccurate and insufficient systems of assessment and placement, multi-semester sequences of developmental math courses, and decontextualized math offerings and instruction that are not relevant to or well-aligned with students' fields of study. Together, these factors slow or stall student progression through developmental math coursework.

2.1 Inaccurate and Insufficient Systems of Assessment and Placement

High-stakes assessment and placement tests are typically used to ascertain whether a student is ready to undertake college-level coursework (Rosales, 2018).

However, the use of a single placement test in a subject area has been found to underestimate the proficiency level of students,⁴ leading some students to take developmental courses when they could have been successful in college-level courses (Fulton, 2012; Scott-Clayton, 2012). Moreover, the use of standardized tests has been shown to be a salient factor contributing to the disproportionate placement of students of color into developmental education (Davis & Palmer, 2010; Preston, 2017). An analysis by Stoup (2015) suggested that more than half of the degree completion gaps observed between White, Black, and Latinx students in a California community college district could be explained by differences in level of initial placement (specifically, how far below college-level students were placed in math and English). As a consequence of the growing awareness of the poor predictive validity of using standardized placement tests, many community colleges are changing placement policies to improve placement accuracy and help more students start out in college-level mathematics. This is discussed in greater detail in a subsequent section.

2.2 Multi-Semester Sequences of Developmental Courses

Students who are considered academically underprepared upon college enrollment have traditionally been placed in multi-semester sequences of developmental courses. These sequences can take up to four semesters to complete. Multi-course sequences introduce multiple exit points, and students assigned to these course sequences are much less likely to complete their program of study and earn a credential (Bailey et al., 2010; Boatman & Long, 2018; Moore, Jensen, & Hatch, 2002).

Importantly, students of color, many of whom are first-generation college students and come from low-income backgrounds, are disproportionately placed in developmental education courses (Attewell et al., 2006; Bahr, 2010; Chen, 2016). Moreover, Bailey et al. (2010) showed that, compared to their peers, underserved students are more likely to be placed in lower levels of developmental courses. When students are placed in lower levels of developmental courses, their course sequences become longer, making them less

⁴ Some students may also be placed into college-level courses that they are not ready for, but this happens much less frequently.

likely to complete these requirements and move on to credit-bearing coursework necessary to earn a degree or other credential.

2.3 Decontextualized Math Offerings and Instruction

One of the factors that may underlie low postsecondary math performance, and in traditional developmental courses in particular, is that students do not find the course content relevant to their lives or fields of study and consequently disengage (Fay, 2017; Hacker, 2016). There is currently a broad debate about the math content and amount of math needed to be successful in various career paths (Charles A. Dana Center, 2020; Hayward & Willett, 2014; Sowers & Yamada, 2015). The content covered in college algebra course sequences is largely relevant for students who intend to take calculus and pursue a Science, Technology, Engineering, or Mathematics (STEM) degree, which is not the intended degree of the majority of students (Rutschow, 2018). Research on postsecondary math instruction suggests that students learn best when their instruction allows them opportunities to think conceptually about math concepts that are relevant to their lives (Quarles & Davis, 2017; Stigler, Givvin, & Thompson, 2010). In addition to its lack of relevance for many students, algebra coursework often functions to “winnow out” students as success rates are low relative to other math options (Burdman, 2018). Traditional developmental course sequences are algebra-based, and often not well aligned to subsequent college-level courses students may take, such as statistics, quantitative reasoning, or liberal arts math.

3. General Reforms to Developmental Math and Their Impact on Inequity

In this section, we provide an overview of current reforms designed to address inaccurate and insufficient systems of assessment and placement, multi-semester sequences of developmental math courses, and decontextualized math offerings and instruction. We discuss these reforms, their underlying theories of action, and, when evidence is available, the impact of these reforms on developmental math inequities. We find that although some reforms are associated with the narrowing of equity gaps in student outcomes, developmental math reforms are not usually designed to reduce barriers specific to underserved students. Consequently, when successful, most

developmental education reforms improve outcomes for students overall but do little to affect equity gaps.

The developmental math reforms discussed in this review fall into four categories: (1) *assessment and placement* reforms that change the way students are assessed for college readiness; (2) *acceleration* reforms that seek to move students more quickly through developmental requirements; (3) *contextualization* reforms that teach students remedial content in the context of their specific field of study; and (4) *curricular and pedagogic* reforms that change the content of mathematics and how it is taught. In the sections that follow, reforms are assigned to one of the four categories. However, in reality, the categories are not mutually exclusive, and many of the reforms described fit into multiple categories.

3.1 Assessment and Placement Reforms

In response to research illustrating the inaccuracy and insufficiency of assessment and placement systems, many state college systems, community colleges, and open-access four-year colleges have changed their placement tests, eliminated the use of these tests altogether, and/or added additional measures to be used alongside the test results.

While many colleges use the College Board's ACCUPLACER test for placement, some colleges and systems have created new placement tests that are better aligned with their curricula and designed to more accurately place students (Kalamkarian, Raufman, & Edgecombe, 2015). Further, many colleges and systems are now using multiple measures to place students into remedial or college-level courses (Fulton, 2012; Rutschow & Mayer, 2018). Multiple measures placement systems sometimes make use of placement test results but also consider other relevant data on incoming students, such as high school GPA and math courses taken in high school. An analysis of the implementation of a multiple measures placement system found that students placed using multiple measures were more likely to enroll in and complete college-level math in their first term, as compared to those placed using a single placement test score. Women appeared to benefit more than men; they were more likely to be placed in a college-level math course and to complete the course with a grade of C or higher (Barnett et al., 2018).

In 2017, California passed legislation requiring colleges to use multiple measures for placement and disallowing placement into developmental education unless the college

can prove that the student's probability of success is higher by taking developmental courses (Seymour-Campbell Student Success Act, 2017). The effects of this legislation on equity are not yet known, but overall completion of college-level math increased by 68% at early implementer colleges (Mejia et al., 2019). Similarly, Florida passed Senate Bill 1720 in 2013, making developmental education optional and allowing students to decide whether or not to take developmental courses. This policy has had positive impacts for all students in college-level math but has not reduced most performance gaps (Park et al., 2018).⁵

3.2 Acceleration Reforms

In response to long developmental course sequences, acceleration reforms help students become ready for college-level courses more quickly and/or minimize exit points or opportunities to leave the developmental sequence before reaching benchmarks of college readiness (Edgecombe, Cormier, Bickerstaff, & Barragan, 2013; Jaggars, Hodara, Cho, & Xu, 2015). Prominent acceleration reforms include curricular modularization, computer-mediated remediation, compressed course sequences, and corequisite remediation.

Curricular modularization reforms. In an effort to move students more quickly to college readiness in mathematics, several states, college systems, and colleges have modularized the content of their developmental mathematics courses (Ariovich & Walker, 2014; Bickerstaff, Fay, & Trimble, 2016; Fain, 2011, 2013; Fay, 2017). Curricular modularization breaks remedial mathematics courses into discrete (often one-credit) chunks and uses diagnostic placement exams to direct students to the specific mathematics content in which they lack proficiency.

Descriptive analyses have shown that diagnostic placement tests and modularized course structures can reduce the number of developmental math credit hours students are required to take (Bickerstaff et al., 2016). Diagnostic placement exams are used to identify which modules students need, and students must complete each required module and enroll in the next to complete their sequence. However, modularization allows only

⁵ One exception is that the policy did narrow performance gaps between Black and Hispanic and White students in intermediate algebra.

some students to accelerate through remedial math requirements. Many students still make slow and limited progress, partly as a result of attrition and partly because modularized course structures place more responsibility on students for time management, self-pacing, and self-directed learning, behaviors that developmental students often lack (Bickerstaff et al., 2016; Fay, 2017). Further, modularization can undermine aspects of mathematical learning that may be particularly critical for remedially placed students, such as developing the ability to see mathematics as a sensible and unified system of thought and building an understanding of concepts that undergird many mathematical procedures (Givvin, Stigler, & Thompson, 2011; Stigler et al., 2010).

Boatman (2012) used a quasi-experimental design to evaluate the effects of remedial reforms at several Tennessee community colleges and found that modularized, computer-assisted models did not negatively affect student outcomes, nor did they show strong positive effects. A recent randomized controlled trial exploring the effects of a modularized, computer-assisted, self-paced approach to developmental math in Texas found no evidence that the modularized program, though well-implemented, was superior to the traditional lecture-based developmental math course (Weiss & Headlam, 2018). We found no research that cast light on the impact of curricular modularization on the outcomes of underserved student groups.

Computer-mediated reforms. Online learning is growing quickly in both the K-12 and postsecondary sectors (Allen & Seaman, 2010; Christensen, Horn, & Johnson, 2008; Means, Bakia, & Murphy, 2014; Miron & Gulosino, 2016). Indeed, with the onset of the COVID-19 pandemic in the spring of 2020, colleges were forced to move their entire curriculum online (Hubler, 2020). Computer-mediated reforms combine teacher-led, classroom-based instruction and computer-mediated instruction in differing ratios, from fully online courses to hybrid courses.

Computer- or software-mediated instruction is thought to potentially deliver more personalized learning tailored to individual students' strengths and weaknesses through diagnostic software, allowing students to focus on particular areas of weakness, make choices about preferred modes of instruction, and receive diagnostic feedback (Means et al., 2014; Twigg, 1999; Wong, 2013). However, research suggests that students have

better outcomes in face-to-face courses than in fully online courses with developmental (Boatman, 2019; Summerlin, 2003) and non-developmental (Bernard et al., 2004; Cavanaugh, Gillan, Kromrey, Hess, & Blomeyer, 2004; Jaggars & Bailey, 2010; Means et al., 2014; Xu & Jaggars, 2013; Zhao, Lei, Yan, Lai, & Tan, 2005) content. Research also suggests that male, Black and Latinx, young, and underprepared students perform particularly poorly in fully online courses, receiving lower course grades and facing higher withdrawal rates than in face-to-face courses (Bork & Rucks-Ahidiana, 2013; Summerlin, 2003; Xu & Jaggars, 2013). An exception is that Zhu and Polianskaia (2007) found that average grades were higher for Black women over the age of 34 in computer-mediated classrooms compared to lecture-based courses.

One type of computer-mediated instruction is the hybrid emporium model, in which students learn at their own pace through a computer-based platform during class time. Recent studies evaluating an emporium model in a high-school-to-college transition math course⁶ offered to students in Tennessee high schools found that the course improved student perceptions of the utility of math, increased their enjoyment of the subject, and lessened a sense of intimidation related to math, particularly among Black students (Boatman & Kramer, 2019; Kane et al., 2018). However, the course did not improve student math achievement or the likelihood of passing a college-level math course (Kane et al., 2018). One study found that students in hybrid emporium models of developmental mathematics in high school or community college were more than 5 percentage points less likely to pass introductory college-level math, though the study did not examine differences by race/ethnicity (Boatman, 2019). Kozakowski (2019) found that students who took a hybrid emporium remedial math course in a state community college system had lower pass rates and lower retention and degree attainment rates than students taking a traditionally instructed remedial math course.

Compressed and corequisite reforms. Compressed and corequisite reforms all seek to reduce the number of prerequisite developmental math courses a student is required to take to demonstrate college readiness or to eliminate them altogether. Within

⁶ Transition courses are senior-year high school courses in math and English designed for students who are not on track to meet benchmarks of college readiness in these subjects, helping them develop the necessary knowledge and skills during high school and avoid assignment to remediation in college (see Barnett, Fay, Pheatt, & Trimble, 2016)

compressed models, developmental math course sequences are shortened to enable students to complete developmental requirements in fewer terms and move more quickly into credit-bearing courses. Within corequisite models, students avoid prerequisite remediation altogether (Edgecombe, 2011; Jones, 2012). Typically, compressed and corequisite courses require revised curricula to better align content with the skills students need to be successful in the relevant college-level courses, which often involves the removal of repetitive or unnecessary content (Barragan & Cormier, 2013; Bragg & Barnett, 2008; Edgecombe, Jaggars, Baker, & Bailey, 2013; Hern & Snell, 2013).

Within this category, corequisite developmental education has emerged as one of the most popular reforms (Complete College America, 2016). Corequisite remediation allows students referred to developmental courses to enter directly into introductory college-level, credit-bearing courses while simultaneously receiving extra academic support to address remedial needs. Corequisite course structures can take a variety of forms. Students may be enrolled in a condensed developmental math course in tandem with a college-level course in a single semester, or may be required to attend tutoring or a math lab in conjunction with the college-level course. Alternatively, the corequisite course curriculum may blend the remedial and college-level material into a single semester-long course (Edgecombe, Cormier, et al., 2013; Fay, 2017).

Using a randomized controlled study design, Logue et al. (2016) found that among students referred to math remediation, those who were assigned to a corequisite statistics course were 16 percentage points more likely to pass that course than those assigned to a developmental algebra course were likely to pass their assigned course. A follow-up study revealed long-term positive impacts resulting from corequisite course-taking, including higher college graduation rates. Ran and Lin (2019) used a quasi-experimental approach to estimate the effects of corequisite remediation in Tennessee on students who were on the margin of the college readiness threshold, finding that corequisite math students were 15 percentage points more likely to pass their first college-level math course than similar students who took traditional developmental math courses. Further, the students requiring remediation who were placed in corequisite courses had similar pass rates in college-level math courses as students who did not require remediation. Much of the positive impact of corequisite remedial reforms in

Tennessee was likely driven by the fact that students took corequisite courses, such as statistics, that were better aligned to their programs of study (Ran & Lin, 2019). In other words, taking a more relevant math course appears to have played a part in improving student outcomes.

There is some evidence that corequisite approaches can improve equity. Research from the California Acceleration Project (CAP) showed that, at one college implementing corequisite remediation along with related reforms, Black students experienced greater improvements than White students in completing college-level math. Black students who enrolled in corequisite math completed college-level math at nine times the state average among Black students. Latinx students who enrolled in corequisite math completed college-level math at four times the state average among Latinx students. White students who enrolled in corequisite math completed college-level math at five times the state average among White students (Henson, Huntsman, Hern, & Snell, 2017). But in an experimental study of corequisite students at three City University of New York community colleges by Logue et al. (2016), the researchers found no changes in gaps among racial/ethnic subgroups with respect to course pass rate differences in college-level statistics, graduation, or rates of transfer to a four-year college (Logue et al., 2019). In this study, being assigned to a corequisite college-level statistics course with workshops (rather than a traditional prerequisite elementary algebra remedial course) improved outcomes for students in all racial/ethnic groups examined but did not narrow equity gaps.

3.3 Contextualization Reforms

In response to decontextualized course content and instruction and low developmental completion rates, some colleges have implemented reforms that integrate foundational math and English skills within the instruction of disciplinary content to heighten motivation and ability to transfer learning (Perin, 2011; Wang, Sun, & Wickersham, 2017).

The Integrated Basic Education and Skills Training (I-BEST) program originated in Washington State's community and technical college system and combines developmental acceleration and contextualization. I-BEST is designed for adults who enroll in a specific career-technical education program and are required to complete

developmental education before they can enroll in their college-level program requirements (Wachen, Jenkins, & Van Noy, 2011). Rather than enrolling in traditional developmental courses, students learn their developmental material in the context of addressing relevant problems in their occupational field of interest while earning college credits. Another important feature of the model is that career-technical faculty work together with developmental instructors to jointly design and team-teach courses.

Two quasi-experimental studies of the I-BEST program have found positive impacts, including increases in basic skills scores and the likelihood of earning college-level credits and a community college credential (Jenkins, Zeidenberg, & Kienzl, 2009; Zeidenberg, Cho, & Jenkins, 2010). A recent experimental evaluation of I-BEST found that the program increased enrollment in college-level courses, credits earned, and credential attainment (Martinson, Cho, Gardiner, & Glosser, 2018).

Wang et al. (2017) found that contextualized approaches in developmental math contributed to increased student motivation and lessened feelings of intimidation and anxiety associated with abstract math. Research by Shore, Shore, and Boggs (2004) has shown that integrating health-related examples and problem-based learning into developmental mathematics for students in allied health programs is associated with significantly higher post-test scores for treated students. We found no research that investigates the impact of contextualized math reforms on student subgroup outcomes.

3.4 Curricular and Pedagogic Reforms

Curricular and pedagogic reforms seek to improve student success in developmental courses by changing math curriculum and/or how it is taught (Fay, 2017). These reforms operate on the assumption that students traditionally assigned to developmental math may benefit from novel approaches to content and instruction in order to become college-ready (Hinds, 2011). Curricular and pedagogic reforms often employ contextualization strategies, such as those discussed with respect to the I-BEST model, and may address metacognitive skills, such as study or self-regulation skills, in addition to math content.

Curricular reforms. The traditional developmental math sequence is designed to prepare students for college algebra and eventually calculus. However, many college students intend to pursue programs of study that do not require calculus. Consequently,

there are increasing efforts to use backward design⁷ principles to create developmental mathematics curricula that prepare students for a range of college-level mathematics courses, such as statistics and quantitative reasoning, associated with non-STEM majors. “Math pathways” reforms offer developmental mathematics sequences in these topics, as an alternative to algebra. Math pathways often employ features of contextualization, in that they are designed to be more relevant to students’ programs of study. They may also be more accelerated than traditional models; most pathways sequences are designed to allow students to complete one developmental and one credit-bearing course within an academic year (Jaggars & Bickerstaff, 2018).

Statway and Quantway, designed by the Carnegie Foundation, are well-known examples of the math pathways approach (Hoang, Huang, Sulcer, & Yesilyurt, 2017). In these models, students enroll in a year-long program that replaces the college’s developmental sequence with a college-level statistics or quantitative reasoning course, depending on which general education college-level math course a student plans to take. Similar math pathways have been implemented by other groups, including the California Acceleration Project and the Dana Center Mathematics Pathways (DCMP) in Texas and other states. DCMP math courses include a focus on collaborative learning approaches and the use of real datasets, while also emphasizing contextualization of mathematics problems in real-life situations. In many colleges, DCMP includes a paired three-credit “student success” course that focuses on how to be a successful student in mathematics and in college more generally.

Rigorous analysis indicates that students in the Statway program are three times more likely to complete college-level mathematics in one year and to earn more college-level mathematics credits in subsequent years than similar students in traditional algebra-based course sequences (Yamada & Bryk, 2016). Preliminary analyses of longer-term outcomes suggest that Quantway students are more likely to earn a two-year degree or credential, and Quantway and Statway students are more likely to transfer to a four-year college, as compared to a general population of community college students (Huang, 2018; Norman, 2017). Subgroup analyses have shown that the program’s benefits are

⁷ Backward design is a method of designing educational curricula that involves setting goals before choosing instructional methods and forms of assessment.

strong for students with a range of prior proficiency levels in mathematics, including those who placed one and two levels below college-ready. Using a propensity score matching approach, Yamada, Bohannon, Grunow, and Thorn (2018) found that Black and Latino men experienced the strongest gains in rates of passing remedial courses and entering college-level math as a result of taking Quantway courses.

A large-scale random assignment study of DCMP is underway, and early results have shown stronger pass rates for students enrolled in the DCMP version of the developmental course. DCMP students are also more likely to attempt and pass college-level mathematics. Further, the impacts of DCMP appear to be greater for part-time students as well as for students who placed into multiple developmental areas (Rutschow, 2018; Rutschow, Sepanik et al., 2019). This research has not examined outcomes by race/ethnicity.

Pedagogical innovation reforms. There is also considerable interest in the idea that students who struggle when taught in traditional ways may benefit from alternative approaches to math instruction (Rutschow, 2018). While there are classroom-level reforms being implemented, there is little information about how changes to classroom practice impact student outcomes (Rutschow, Cormier, et al., 2019).

One example of a reform that changes instructional practice and that has been studied is CUNY Start, an intensive, pre-matriculation program designed to prepare students to enter college-level courses and to build literacy, numeracy, and student development skills.⁸ CUNY Start is different from traditional developmental education because it relies on student-centered pedagogical techniques⁹ that have been shown to increase engagement and academic success (Boylan, 2002; Grubb et al., 1999; Simpson, Stahl, & Francis, 2004). The instructional model emphasizes questioning to elicit student thinking and discussion, problems based in real-world contexts to develop conceptual understanding, and explicit attention to students' organizational and study habits.

⁸ CUNY Start was initially designed to help students pass the GED test and gain their high school equivalency. It evolved into a program to help students pass college placement tests and become college-ready.

⁹ Student-centered learning is designed to make students comfortable expressing their ideas, questioning what they learn, and learning from mistakes. Greater agency in one's learning is expected to increase student engagement with the learning process, understanding, and performance.

Students interviewed during an implementation study of CUNY Start reported enhanced engagement, learning, and confidence (Bickerstaff & Edgecombe, 2019). Compared to their peers in traditional developmental education, CUNY Start participants were found to be more likely to become college-ready in a greater number of developmental areas (math, reading, and writing) and are more likely to return and enroll for a second semester of college. The positive impact of CUNY Start on college readiness did not vary by race/ethnicity (Scrivener et al., 2018).

4. Addressing Equity in Reforms to Developmental Math Education

Thus far, many developmental math education reforms have resulted in improved attainment of certain postsecondary outcomes, and assessment and placement policy reforms, corequisite remediation models, and some hybrid computer-mediated models have in some cases contributed to a reduction in equity gaps. In order to further eliminate gaps and create equity in student outcomes, the next wave of reforms must focus squarely on equity and address policies and practices that disadvantage underserved students.

In this section, we highlight several areas of focus for future reforms aimed at improving equity in developmental math performance. The literature suggests that underserved students are most successful in mathematics when there are active efforts to address the specific factors that contribute to inequity. These factors include stereotype threat, math anxiety, implicit biases of teachers, and tracking. While there are other causes of inequities in mathematics achievement, such as living in poverty, housing or food insecurity, poor school facilities, and inadequate school funding, this review focuses on the practices that education leaders have the power to change.

4.1 Stereotype Threat and Math Anxiety

Stereotype threat occurs when members of a social group “deal with the possibility of being judged or treated stereotypically, or of doing something that would confirm existing negative images of their identity” (Steele & Aronson, 1998, p. 401). Numerous studies conducted at both the K-12 and postsecondary levels have demonstrated that stereotype threat negatively impacts and emotionally burdens groups that have been stigmatized as low performing or academically deficient (e.g., Cadinu,

Maass, Frigerio, Impagliazzo, & Latinotti, 2003; Schmader & Johns, 2003). When reminded of the stereotypes about their race prior to taking a test, Black students perform less well (Steele & Aronson, 1998). Of those impacted by stereotype threat, students who strongly identify with their academic abilities suffer the most from the stigma of intellectual inferiority such that high-achieving students of color are more likely to drop out of school compared to high-achieving White students (Osborne & Walker, 2006).

Mathematics anxiety is the feeling of tension, apprehension, or fear that interferes with one's ability to perform mathematics (Ashcraft, 2002). Similar to stereotype threat, math anxiety also results from internalized fears and stereotypes that inhibit students' ability to see themselves as mathematically capable learners. As with stereotype threat, Black students are more likely than other racial/ethnic groups to experience the debilitating effects of math anxiety on math performance (Rech, 1994). Studies have shown that math anxiety is negatively associated with students' performance on standardized mathematics tests, grades in mathematics courses, plans to enroll in advanced high school mathematics courses, and selection of mathematics-related college majors (Engle, 2002; Miyake & Shah, 1999; Ramirez, Shaw, & Maloney, 2018).

Recent research has moved beyond identifying these two issues to determining the mechanisms through which they impact student performance. Though stereotype threat and math anxiety might arise for different reasons, recent research has found that they operate similarly in how they interfere with math performance (Maloney, Schaeffer, & Beilock, 2013). Both negative stereotypes and anxiety or doubt about math abilities reduce students' working memory capacity. Focusing on negative stereotypes in addition to the math task at hand limits students' ability to retain information and to perform well on exams (Ashcraft & Kirk, 2001; Beilock, Rydell, & McConnell, 2007).

Journaling to identify one's feelings about math has been shown to be successful at freeing up valuable working memory space formerly occupied by negative perceptions of one's self (Ramirez & Beilock, 2011). In addition, learning about the concepts of math anxiety and stereotype threat have also been found to mitigate the impact of these factors in women and may be promising for underserved racial/ethnic groups (Johns, Schmader, & Martens, 2005).

Strategies to combat stereotype threat also involve maximizing students' confidence in their academic aptitude, including abilities specific to math. One solution is to change the way that teachers provide feedback to students. The experience of stereotype threat is associated with a heightened sensitivity to negative feedback, because a student may perceive criticism as confirmation of their inability to succeed academically, leading to a loss in motivation (Spencer, Steele, & Quinn, 1999). Research in a postsecondary setting found that students scored more positively on measures of motivation when instructors buffered their negative feedback by explaining the standards expected in a class and affirming the students' capacity to reach those standards, compared to when students received only negative criticism (Cohen, Steele, & Ross, 1999).

Another means to address stereotype threat is to promote a sense of belonging and efficacy for students (National Commission on Social, Emotional, and Academic Development, 2019). Walton and Cohen (2007) evaluated the impact of an intervention designed to mitigate doubts students had about their social belonging in college. The intervention raised the college grades of Black students but not White students. The early work of Uri Treisman also supports the claim that a sense of belonging impacts learning and academic outcomes in STEM courses. When comparing the college performance of high-achieving Asian students entering college taking STEM courses to high-achieving Black students doing so, Treisman found that Asian students performed better because they integrated their academic and social lives, studying and completing assignments in groups, while Black students tended to study alone (Asera, 2001). Treisman created an initiative called Emerging Scholars designed to help Black students work together to solve math problems and identify themselves as capable mathematicians.

Opportunities for collaborative learning have also been found to reduce math anxiety in community college developmental math classrooms. Research suggests that when students can help and learn from each other, it creates a safe and nurturing space for learning, which improves student performance (Bonham & Boylan, 2011; Galbraith & Jones, 2006). Another study conducted in an urban community college found higher test scores and lower anxiety among students who learned math more conceptually as

compared to those who learned math more procedurally (Khoule, Bonsu, & El Houari, 2017).

General reforms to developmental math do not address the specific struggles that can leave underserved students feeling inadequate and unable to excel. Research has shown that students have deeply held beliefs about their ability to be successful in math, and academic progress can be shaped by these beliefs (Stevens, Olivárez, & Hamman, 2006). This is illustrated in some interesting consequences in states and community college systems that have reformed their assessment and placement practices to allow students to place themselves into developmental or college-level courses. Kosiewicz and Ngo (2019) found that Black, Latinx, and female students were most likely to place themselves in lower-level courses. In sum, stereotype threat and math anxiety may be mitigated by course materials and pedagogy that increases students' sense of belonging and efficacy.

4.2 Instructor Bias

Whether conscious or not, bias can lead instructors to lower their expectations of students' mathematics abilities, especially for students of color. Boysen, Vogel, Cope, and Hubbard (2009) found that instructor bias in college classrooms is oftentimes more subtle than overt and blatant, suggesting that instructor bias may be expressed through microaggressions. College students who routinely experience microaggressions report feeling despondent and doubtful of their academic abilities, causing many to drop a class, change their major, or attend college elsewhere (Solórzano, Ceja, & Yosso, 2000). K-12 research has found that despite organized efforts to close equity gaps in performance among students of different backgrounds, instructors' implicit biases perpetuate inequitable student outcomes (Johnson, 2018).

Studies suggest that instructor bias can be reduced and even eliminated when instructors are encouraged to participate in reflective teaching as a normative pedagogical practice (Lin, Lake, & Rice, 2008; Marcos, Sanchez, & Tillema, 2011). This practice encourages instructors to journal about their teaching decisions daily, allowing them to become more aware of their implicit biases by paying attention to how they think and behave in the classroom (Vrouvas, 2017). Other studies suggest that instructors should receive training in faculty seminars and learning center workshops to identify their own

biases in the classroom and decrease the effect of their biases on students (Boysen et al., 2009). Research suggests that creating an instructional culture in which math teachers maintain high standards and equitable practices for all students can mitigate some of the biased treatment underserved students receive, positioning teachers as allies rather than obstacles to achievement.

4.3 Tracking

Tracking is a structural factor at the K-12 and college level that, if removed, could improve the outcomes of underserved groups. Tracking is the practice of separating students and putting them on different academic trajectories based on their perceived abilities (Deil-Amen & Deluca, 2010; Parpart, 1995; Siegle, McCoach, Gubbins, Callahan, & Knupp, 2015;). Tracking is present in high school and college and can take several forms. Students may be placed into academic, general, or vocational trajectories, or sorted into high-ability and low-ability courses (Gamoran, 2010). This practice disproportionately places underserved groups in lower and vocational tracks, often limiting their access to rigorous coursework that can better prepare them for college or the workforce (Banerjee, 2016; Schudde & Meiselman, 2019; Solórzano & Ornelas, 2002). In K-12, Siegle et al. (2015) found that, even after controlling for school characteristics and prior student achievement, tracking typically advantaged White students in their sample, whose odds of being identified as gifted and placed in a higher track were 2.5 times higher than that of Black students. Ngo and Velazquez (2020) have argued that only a minority of students experience “math mobility”—progressing to higher levels of math than what they were studying in high school—as they transition to community colleges. Black and Latinx students are the least likely to experience math mobility, and they are especially likely to be caught in patterns of course repetition from which they never emerge (Ngo & Velazquez, 2020).

Researchers have suggested that to mitigate the negative effects of tracking, policymakers should set limitations and restrictions on the practice of tracking and reallocate resources to better support the learning of students in lower tracks (Wheelock, 1994; Braddock & McPartland, 1990). Practitioners who have organized against tracking found that best practices for de-tracking include restructuring curriculum and pedagogy for the learning of all students, regardless of ability, and building a more cohesive

community experience within the classroom (Rubin, 2006). In some San Francisco and Oregon school districts, there are multiple pathways that lead students to rigorous coursework regardless of their abilities (Daro & Asturias, 2019).

Researchers have also noted that instructors and administrators must reshape their own views on students' ability to engage in rigorous math (National Council of Teachers of Mathematics, 2018). And researchers have pointed out that developmental education is itself a form of tracking that diverts students into pre-college-level courses based on an assessment of their math ability (Scott-Clayton & Rodriguez, 2015). Dispensing with pre-college developmental math courses and starting all students at college-level with integrated remedial support (as is done in the corequisite developmental approach) as well as using a pedagogy that increases a sense of belonging and efficacy has the potential to address inequities associated with the practice of tracking, which is pervasive throughout the current system of math course-taking.

5. Conclusion

While more students are enrolling in college-level math courses as a result of existing reforms to developmental math education, inequities in both student placement into developmental math courses and completion of such courses persist and contribute to equity gaps in rates of degree attainment and transfer (CUNY Taskforce on Developmental Education, 2016). The nationwide reform movement to improve student outcomes in developmental math courses is promising. However, as we describe in section 3 of this paper, these reforms are typically designed to improve outcomes in developmental math for the general student population. Consequently, these reforms “raise all boats” but often do little to reduce inequities between advantaged and underserved students.

In order for reforms to reduce and eliminate inequities, they must do more than address issues that all students face. We recommend that colleges:

- create and use developmental and college-level math curriculum and instruction that affirms students' math ability and improves their confidence,

- engage in student-centered instructional practices that encourage conceptual understanding of math and give students a sense of ownership over their own learning,
- provide professional development to faculty to help identify and remediate instructor biases,
- develop policies and practices that prevent the tracking of underserved students into less rigorous math courses and/or developmental education, and, similarly,
- consider ways to increase access to STEM courses for Black and Latinx students.

Colleges must create specific equity goals and implement reforms that can mitigate the factors that contribute to inequity. Many of the obstacles faced by underserved students, such as math anxiety, stereotype threat, and instructor bias can be addressed through changes to policy and practice. Ideally, these changes would happen beginning at the K-12 level, but there is still a lot of work postsecondary institutions can do. We point to pedagogical and curricular innovations as an area ripe with potential to eliminate inequities in developmental math placement and completion. It is worth noting that several of the equity-minded changes proposed are deeply entwined with cultural changes and must therefore address the underlying values and assumptions of faculty and administrators in community colleges. Cultural changes are unlikely to occur without core changes to fundamental beliefs. Consequently, this type of change is typically a long-term process (Kezar, 2018). But if colleges prioritize equity as a goal, they will move closer to ensuring that all students have an equal opportunity to excel in college math.

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