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Workshop on Understanding Success and Failure of Students in Developmental Mathematics:
Developmental Mathematics Reforms

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Nearly 70 percent of incoming students at two-year colleges and 40 percent of incoming students at four-year colleges enter college taking developmental, or remedial, classes.[1] Developmental courses are generally offered to students who are assessed as having pre-collegiate skill levels in math, reading, or writing. Moreover, they are traditionally offered as pre-requisite, multi-course sequences, with students required to pass each successive level before entering a college-level course. These courses can take multiple semesters to complete, and they are generally offered as noncredit courses, meaning that they do not count towards a college degree and are costly undertaking for students.

Recent research has questioned the efficacy of these courses, revealing that students taking developmental courses rarely progress to, let alone pass, college-level courses. For instance, a national study from 2016 revealed that fewer than half of students enrolled in developmental courses at two-year institutions completed these courses and only 59 percent of four-years students completed them.[2] Similarly, when comparing the long-term success of students with similar skill levels placed into developmental versus college-level courses, few long-term positive effects from developmental courses, and in some cases, negative effects on students' college progress were observed.[3] Other research has shown that students are often overly placed into developmental courses and that these students may have done well had they been placed directly into college-level courses.[4]

Developmental math, in particular, has been an area where students have struggled. National studies have shown that large proportions of students in both two-year (59 percent) and four-year (33 percent) colleges are taking remedial math, with the average student taking two to three successive courses at these institutions.[5] Many students enrolled in these courses do not complete them: only 50 percent of those at two-year colleges and 58 percent of those at four-year colleges completed all their developmental math requirements.[6] While few longitudinal studies of students taking remedial courses have been conducted, previous research has shown that as

[1] Chen (2016).
[2] Chen (2016).
[3] Bettinger and Long (2009); Boatman and Long (2010); Calcagno and Long (2008); Martorell and McFarlin (2011); Valentine, Konstantopoulos, and Goldrick-Rab, (2017); Melguizo, Bos, Ngo, Mills, & Prather (2016).
[4] Jaggars, Edgecombe, and Stacey (2014); Bailey et al. (2015); Belfield & Crosta (2012); Scott-Clayton, Crosta, & Belfield, (2012)
[5] Chen (2016)
[6] Chen (2016).

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low as 20 percent of students taking remedial math go on to successfully complete a college-level math course.[7]

Given these challenges, math has been a particularly strong area for reform, as many see developmental math as one of the key stumbling blocks to students' college success. Many practitioners and policymakers have been experimenting with ways to improve the methods used to assess students' college readiness, their placement into courses as well as the format, sequencing, and content taught within them. For instance, nineteen states now allow for the use of multiple measures (such as the use of high school performance along with scores on a standardized test) in assessing college-readiness, with the hope that including measures such as high school performance or motivation alongside standardized test information may improve the accuracy of placement decisions.[8] Other reforms have focused on revising the structure, content, and pedagogy in developmental and college-level math courses. For instance, compressing multiple developmental courses into one class, enrolling students directly into college-level courses with supports, and revising math curriculum and pedagogy to better align with students' intended careers and to better engage them in the learning process are a few of these approaches.[9] Finally, some reforms seek to provide students with more directed supports and structure throughout their college career in order to incorporate students' developmental coursework into their longer-term college trajectory.[10]

This paper discusses the range of existing developmental math reforms currently being implemented and tested across colleges and universities in the U.S. It will describe the most common models, the students they target, the relative scale of these programs across the U.S., and the current research documenting their effects on students' outcomes. This paper will privilege rigorous research studies, such as randomized control trials (RCT) or studies that attempt to control for differences in students' baseline characteristics, when discussing effects on student outcomes. However, it will also discuss descriptive research when rigorous research is not available to consider a reform's potential promise for improving developmental math students' outcomes when rigorous research is not available. The paper will conclude with an assessment of where the field currently stands and provide an outlook on future work and research.

Historical Context on Developmental Mathematics Courses

As enrollments in higher education increased in the latter half of the 20th century and many colleges offered open admissions, two-year and four-year colleges and universities became more focused on supporting students who entered college needing to improve their basic skills.[11]

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7 Bailey, Jeong, and Cho (2009).
8 Education Commission of the States (2018).
9 Zachry Rutschow and Schneider (2011); Logue, Watanabe-Rose, and Douglas (2016); Strother, Van Campen, and Grunow (2013); Cullinane (2013).
10 Scrivener, Weiss, Ratledge, Rudd, Sommo, and Fresques (2015); Bailey, Jaggars, and Jenkins (2015).
11 See Roueche and Roueche (1993), p. 41 – 48, for a discussion of the history of developmental education.

Starting in the 1970s, national organizations were formed to promote the development and discussion of remedial (as previously known as) education, with many organizations publishing research on promising practices for assessment, placement, instruction, and administration of these courses.[12] However, few of these studies attempted to more rigorously evaluate the outcomes of students in these courses or the types of models or dosage that might be most effective.[13]

Though researchers identified "promising practices" for the courses, no generally accepted standards for how these courses were to be organized and thus structured existed, and consequently content varied across colleges. For instance, colleges might offer anywhere from one to five levels of developmental coursework, with varying methods for assessing students' skill levels and varying decision-making processes for placing them into these courses. Alternatively, some colleges might use standardized assessments to assess students' skills and mandate the completion of a certain number of developmental courses before enrolling in college-level courses, while others might not assess students' skills nor require them to take developmental courses at all.[14]

Although many practices differed across colleges, mandated assessment and placement into developmental courses was a recommended practice prior to the turn of the century, and many colleges implemented these recommendations.[15] In 2010, 100 percent of two-year colleges and 85 percent of four-year colleges reported using standardized test scores, such as the SAT and ACT admissions tests to place students or the ACCUPLACER and COMPASS placement tests.[16] Colleges also offered numerous developmental math courses; the average college offered 3.6 remedial courses in 2000.[17] Additionally, the majority of students entering two-year colleges were assessed as needing two or more of developmental math courses, meaning that many of these students would require a full year of developmental math before entry into college-level math courses.[18]

Traditionally, developmental math courses have also been focused on developing students' algebra skills in order to prepare them for college-level algebra, a traditionally, required course for most two-year and four-year majors. The lowest level developmental math courses generally focus on developing students' basic arithmetic skills before moving on to pre-algebra, elementary algebra, and intermediate algebra, requiring students testing at the lowest levels to enroll in and pass each successive course before entering college-level algebra.[19]

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[12] Boylan (1985, 2002); Boylan, Bliss, and Bonham (1997); McCabe (2000); McCabe and Day (1998); Roueche and Roueche (1993, 1999); Starks (1994).
[13] Zachry Rutschow and Schneider (2011).
[14] Boylan (1985, 2002); Boylan, Bliss, and Bonham (1997); McCabe (2000); McCabe and Day (1998); Roueche and Roueche (1993, 1999); Starks (1994).
[15] Bailey, Jaggars, and Jenkins (2015).
[16] Fields and Parsad (2012). Note that the COMPASS test was retired as a placement test in 2015.
[17] Bailey, Jeong, and Cho (2009).
[18] Bailey, Jeong, and Cho (2009).
[19] Stigler, Givven, and Thompson (2013).

Outside of the content taught, less is known about the typical instructional practices employed in developmental courses, though researchers have been increasingly calling for more work.[20] However, previous [21]studies have shown that many developmental courses may suffer from the same types of drill-and-kill instruction present in many classrooms throughout the U.S. International studies of K12 instruction have shown that math instruction in the U.S. is often characterized by a focus on learning and practicing routines and less on math concepts, whereas math instruction in high achieving nations focuses on actively engaging students in understanding mathematical concepts.[22] More recent studies of developmental courses have confirmed this theory, noting that instruction in these courses is characterized by a sequentially ordered focus on discrete subskills often on tasks that have little resemblance to college-level work.[23] Others have also shown how the divide between students' experiences and expectations can also be a challenge to their success.[24]

Reforms to Developmental Mathematics

The section below provides an overview of the most common reforms to developmental math education. These reforms are divided into five sections: (1) reforms to assessment and placement, which discuss changes to how students' college-readiness is assessed and the mechanisms used to place them into developmental courses; (2) structural and sequencing reforms, which focus on reforms that primarily rely on changing the timing or sequencing of developmental math courses; (3) instructional reforms, which focus primarily on changing the content or pedagogy in developmental math classes; (4) support reforms, which focus on providing additional supports to students enrolled in developmental math classes; and (5) comprehensive reforms, which focus on multiple aspects of students' college careers in an effort to improve the success of students in developmental courses. Some of the reforms listed below integrate multiple components, thus the categorization is somewhat loose. Additionally, some of the reforms can be inclusive of developmental reading and writing as well as developmental math.

[Insert Table 1. List of reforms and descriptive summary of each]

1. Assessment and Placement Reforms

This section describes three common reforms to developmental assessment and placement, which are aimed at more accurately diagnosing students' skill levels and their placement into developmental or college-level courses. Additionally, it discusses early assessment programs, whereby high school students' college readiness is assessed and students are allowed opportunities to work on advancing any needed skills while still in high school.

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[20] Grubb (2013); Mesa, Wladis, and Watkins (2014).
[21] Lutzer (2007); Goldrick-Rab (2007); Grubb (1999).
[22] Stigler & Hiebert (1999); Hiebert (2003).
[23] Armstrong, Stahl & Kantner, (2015); Grubb (2013).
[24] Cox (2011).

Multiple measures assessment

Reforms to assessment and placement process in developmental education generally focus on developing new mechanisms for assessing students' skills upon college entry and for decision-making around course placement. As noted above, two-year and four-year colleges and universities have traditionally assessed students' readiness through the use of standardized exams. However, with the research revealing that standardized tests may not be the best predictor of students' college readiness or success, practitioners and policymakers have looked to consider other measures of students' potential. The most popular of these measures is the inclusion of high school performance information, such as grade point average, the highest level of a course taken, or the number of courses taken in a particular subject.[25] Additional measures that might be considered are the results from non-cognitive tests, which measure students' motivation, commitment or students' own perceptions of their abilities.[26]

Multiple measures assessment reforms generally combine alternative measures of students' skills together with a standardized test. Decision-making about where students are placed can be made in variety of ways. For instance, colleges may use a waiver system, whereby one or more measures is used to exempt students from developmental courses. Alternatively, colleges might employ an algorithm that weighs various measures, providing an overall recommendation for placement based on a combination of the measures together. Multiple measures assessment has been implemented both in developmental reading and writing as well as developmental math placement decisions.

The target group for assessment reforms can vary from the entire population of students entering a postsecondary institution to select groups of students, such as those that are recent high school graduates, those that have higher scores on a standardized test, or older students. Multiple measures assessment reforms have also become highly popular, with 19 states now allowing for or encouraging the use of multiple measures assessment for entering students.[27] For instance, North Carolina and California both required the use of multiple measures in 2016 and 2017, respectively.[28] A national survey in 2016 found that 57% of public two-year colleges now use multiple measures in math assessment, an increase of 30 percentage points since the last national survey was conducted in 2011.[29]

A number of studies have found that multiple measures assessment, and in particular the use of high school performance information, can increase the accuracy of developmental education placement.[30] The Center for the Analysis of Postsecondary Readiness (CAPR) is currently conducting a randomized control trial study of a multiple measures assessment system

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[25] Fong and Melguizo (2016).
[26] Barnett, Bergman, Kopko, Reddy, Belfield, and Roy (2018); Fong and Melguizo (2016); Ngo, Chi, and Park (Forthcoming)
[27] Education Commission of the States. (2018).
[28] Barnett, Bergman, Kopko, Reddy, Belfield, and Roy (2018).
[29] Zachry Rutschow and Mayer (2018).
[30] Hodara, Jaggars, and Karp (2012); Belfield & Crosta (2012); Marwick (2004); Dadgar, Collins, & Schaefer (2015); Ngo and Kwon (2015).

in the State University of New York, and early impacts reveal positive effects on students' placement into college level courses, college-level course enrollment, and college-level course completion. Particularly in math, students in the program group, which were placed using multiple measures, were 3.1 percentage points more likely to enroll and complete a college-level math course (impacts were higher for English with a 12.5 percentage point difference between program and standard students) than a control placed with traditional measures.[31] Finally, a recent quasi-experimental study on Florida's developmental education redesign, which requires colleges to use high school grades to determine students' readiness, suggests that those with higher levels of preparation in high school do better in college-level courses.[32]

Diagnostic assessments

Rather than using blunt standardized assessment scores, some colleges and universities have looked to implementing assessments that pinpoint particular challenge areas for students, which are then used to guide developmental course placement. Diagnostic assessments have often been used by teachers after students are assigned to classes to determine areas of strength and weakness, which teachers then use to guide their instruction. However, some states, such as Virginia, North Carolina, Texas, and Florida,[33] have diagnostic assessments that colleges can (or are mandated to) use to place students into developmental courses. [34] Individual states or colleges may use one of a number of commercially available diagnostic assessments, such as ALEKS, ASSET, or Pearson's ACCUPLACER//MyLab Foundations Skills, while other states may develop a customized exam for their own state.[35] Diagnostic assessments are often used in concert with structural reforms, such as the modularization of developmental courses into smaller skill "modules," where students only take the courses they need prior to entry into college-level courses (see modularized courses below).

The target group for diagnostic assessments can range from all entering students to specific groups of students, such as those that have high scores on more generalized placement exams or those who may need instructional support in multiple areas. It is difficult to know at what scale diagnostic assessments are being used in various states and colleges, as they are often listed along with a number of other possible exams that could be used to assess college readiness. However, eight states allow colleges the option to use a diagnostic exam to assess and place students into developmental courses.[36] Research on the effectiveness of diagnostic assessment is relatively limited, though one quasi-experimental study found that diagnostic assessments were

[31] Traditional measures were generally standardized assessments. Multiple sites were included in this study and they had slightly varying placement processes.
[32] Woods, Park, Hu, and Jones (2018).
[33] Florida policy no longer requires graduates of Florida high school to take developmental courses; however, students have the option to take the Florida Postsecondary Education Readiness Test if they wish to: http://www.fldoe.org/schools/higher-ed/fl-college-system/common-placement-testing.stml
[34] Hodara et al. (2012); Daugherty et al. (2018).
[35] American College Testing Program (2019); McGrw Hill (2019); Pearson Education (2019); Ngo and Melguizo, (2015).
[36] ECS (2018). States: FL, NC, VA, KY, LA, ND, TX, VA.

more effective at placing students than computer adaptive tests[37] A scant amount of literature is also available discussing the theory behind these models.[38]

Early assessment and transition programs

Some colleges and states are experimenting with early assessment programs, which provide assessments to students while they are still in high school and allow them to work on building their college-readiness before high school graduation. Generally, students' skills are assessed through a college entrance exam, such as the SAT or ACT; a college placement exam, such as the Accuplacer; or a Common Core-aligned test, such as Smarter Balanced. Students that score below a certain level (such less than a 19 on the ACT) are generally referred to take a transition course while still in high school. [39] These courses can be offered in a variety of formats ranging from online tutorial programs to classroom-based instruction.[40] One example is Tennessee's Seamless Alignment and Integrated Learning Support (SAILS) program, which integrates the Tennessee Board of Regents learning standards into the math course that students take in their senior year. The course is specifically designed for students with low scores on the ACT (18 or below) and provides instruction through a hybrid classroom and online learning environment.[41]

California is also implementing a similar program called the Early Assessment Program (EAP). In this program, high school juniors take the Smarter Balanced Summative Assessments for English language arts/literacy (ELA) and mathematics, which serve as an indicator for college-readiness for the California State Universities and the California Community Colleges. Based on the results of this test, students are given one of four status levels, ranging from college ready to not ready. If certified as college ready, the student can register directly into college-level courses; if not college ready, students take courses at their high schools to build their skills.[42]

The adoption of early assessment and transition courses is growing across the U.S, and in 2017, high schools in 39 states offered transition courses as part of their programming, demonstrating an increase of 10 states since 2012-2013.[43] However, descriptive and quasi-experimental evaluation research on these methods shows somewhat mixed results regarding students' math success. Descriptive studies in Arkansas, Mississippi, and Tennessee have shown high levels of completion of the transition courses and, in Arkansas and Mississippi, increases in students' skills, as assessed on the ACT exams.[44] Overall, quasi-experimental studies in Florida, California, New York, and Tennessee have found that students who participated in these

[37] Ngo and Melguizo (2015).
[38] McGraw Hill (2019).
[39] Barnett, Chavarin, and Griffin (2018).
[40] Fay, Barnett, and Chavarin. (2017).
[41] Tennessee Board of Regents (2019).
[42] California Department of Education (2019).
[43] Barnett, Chavarin, and Griffin (2018)
[44] Tennessee Board of Regents (2019); Southern Regional Education Board (2017).

programs tended to have a higher likelihood of placing into college-level math courses.[45] However, higher placement did not always translate into higher college-level math completion rates. Only in the New York study was a small, statistically significant gain seen in college-level math pass rates (1 percent); there was no statistically significant change in college-level math pass rates in the others. Additionally, another study of transition courses in West Virginia found that these courses had no effect on students' college readiness and negative effects on students' likelihood of passing a college-level math course.[46]

2. Reforms to the Structure and Sequencing of Developmental Courses

This section describes reforms that seek to improve students' progress to and through developmental courses. In general, these reforms rely on changing the structure of developmental courses to accelerate students' time in these courses by compressing course content into shorter time periods, breaking apart development courses such that students receive instruction only in the skills they need, or by providing developmental supports in conjunction with college-level classes. These reforms may also be paired with other assessment, instructional, or support reforms in colleges' implementation; thus, these reforms should not be seen as mutually exclusive of other methods.

Bridge courses and non-course based options for skill-building

Many colleges have been experimenting with offering entering students who are assessed as in need of developmental courses, the opportunity to learn these skills outside of the traditional course context. Rather than offering classroom-based courses, colleges have offered shorter-term skill building sessions either before the semester starts (often called summer bridge programs or boot camps) or through non-course based options during the school semester, such as working on skills through a technology program in the computer.

Alternatively, colleges sometimes offer students the opportunity to receive supports and tutoring outside of class, such as online tutorials, which can be taken in a computer lab or at home. Some states, such as Texas, Connecticut, and Colorado, have used these types of non-course based options to replace their lowest levels of developmental education. Rather than offering multi-level, pre-requisite developmental course sequences, these states have limited their colleges to offering only one or two developmental course levels in each subject, and refer students testing at lower levels (usually below the 9th grade) to non-course based option (NCBO) "transitional" supports.[47] These states have also recommended that colleges refer these students to local adult basic education programs, which have traditionally provided literacy, numeracy, ESL, and high school equivalency exam preparation for adult learners.

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[45] Trimble, Pheatt, Papikyan, & Barnett, 2017; Mokher, Leeds, and Harris (2017); Kane, Boatman, Kozakowski, Bennett, Hitch, and Weisenfeld (2018).
[46] Pheatt, Trimble, & Barnett, 2016
[47] Visher, Cerna, Diamond, and Zachry Rutschow. (2017)

The primary goal for students enrolled in boot camps and NCBOs is to help students strengthen their skills so that they can retake the placement exam and place directly into college courses or into higher level of developmental courses. Additionally, given the short-term nature of boot camps and NCBOs, students enrolled in these services are generally not considered traditional college students (unless they are enrolled in other college courses) and are generally not enrolled nor tracked in colleges' databases. Additionally, boot camps and NCBOs are not generally eligible for federal financial aid. As such, colleges generally provide these services to students free of charge or at a nominal fee.[48]

The target group for boot camps and NCBOs can range from all students assessed as needing developmental courses to only select groups of students, such as those who receive assessment scores near the college-level course cutoff (who could then move into college courses with some short-term skill building) or those with lower scores (who could potentially place into higher level developmental or college level classes). To date, boot camps or NCBOs are being formally implemented in five[49] states, though individual institutions may also choose to offer them on their own.

Research on summer bridge programs at four-year institutions have shown some positive outcomes:[50] a quasi-experimental research study conducted in 2010 of a 5-week summer bridge program at a four-year university, found statistically significant impacts on graduation rates for students who took the bridge course.[51] A randomized control trial study of summer bridge programs in eight Texas community colleges in 2012 revealed that summer bridge programs had no effects on students' credit accumulation or persistence. An effect was seen on first college-level course completion in math and writing, the first year and a half; however, no significant differences were detected after two years.[52] There is also an additional regression discontinuity study currently underway of boot camps for students placing into lower levels of developmental math and results from this study are expected in 2019.[53]

Compression of developmental courses

Some colleges have sought to reduce students' time in developmental courses by compressing course content into shorter time periods, such as a multi-week or half a semester course. Colleges will often offer two of these compressed courses in one semester, such as offering the 8-week developmental math course followed by 8-week college-level math or two developmental courses in one semester. This two-in-one semester sequencing allows students with one developmental course need to complete both their developmental and college-level coursework in one semester, and students needing two developmental courses to complete their developmental coursework in one semester. When offering compressed courses, colleges may

[48] Visher et al (2017).
[49] Daughtery et al. (2018); ECS (2018). States: CO, CT, KY, MS, TX.
[50] Garcia (1991); Ackermann (1990)
[51] Murphy, Gaughan, Hume, & Moore (2010).
[52] Barnett, Bork, Mayer, Pretlow, Wathington, and Weiss. (2012).
[53] Visher et al (2017).

either cut some of the original course content to fit the course into a shorter time period or offer the compressed course more intensively (i.e., five days a week rather than three days a week).

An example of a compression model was implemented at the Community College of Denver. At this college, two developmental courses were paired together in one semester, allowing a student to complete either the lowest and middle level of developmental courses or the middle and highest developmental courses—or two courses in one semester. This program implemented other supports as well, including case management and mandatory tutoring.[54]

In 2016, 51% of public two year colleges offered compressed courses and three states currently encourage their use along with other types of developmental education reforms. [55] However, few rigorous studies have looked at the outcomes from compressed developmental courses. Nevertheless, descriptive studies tend to show promising trends: students in compressed courses had higher success rates than those in traditional courses. [56] Additionally, a quasi-experimental study of Community College of Denver's program that compared students in compressed courses with a matched set of peers found that students in compressed courses were more likely to complete a college-level math course within three years.[57]

Co-requisite models

One of the most popular, current developmental math reforms are co-requisite courses, which allow students testing at the developmental level to enroll directly into college-level courses with added supports. Originally implemented in three universities in Tennessee, co-requisite courses have become one of the most common methods for redesigning developmental math courses in the past few years.[58] Though a national survey of public two-year colleges in 2016 found that only 16% of colleges were implementing these reforms in math, many states now recommend or mandate these reforms for their colleges. For instance, in 2018, the Education Commission for the States found that of the 19 states that had developmental course reforms, 15 states recommended or mandated co-requisite reforms.[59]

Co-requisite models can take a variety of forms. For instance, at Austin Peay State University, where one of the original co-requisite models was implemented, developmental courses were eliminated entirely and students were placed directly into college-level math courses that were linked with tutoring workshops.[60] Other models can include stretching college-level math courses over a longer period of time (for instance, course work is offered across two semesters or course work in one semester is offered more intensively, such as five times a week) or offering college-level math paired with a developmental math course.[61] Co-requisite courses

[54] Edgecombe, Jaggars, Baker, & Bailey (2013)
[55] Zachry Rutschow and Mayer (2018); ECS (2018). States: Arkansas, Florida, New York
[56] Sheldon and Durdella, 2010; Zachry (2008); Adams (2003); Brancard, Baker, and Jensen (2006); Bragg (2009)
[57] Jaggars, Hodara, Cho, and Xu (2014).
[58] Boatman (2012).
[59] ECS study: AK, CA, CO, CT, FL, GA, KY, LA, NV, NY, NC, N, OH, TX, WV. 4 other states that recommend policies not including co-req courses.
[60] Boatman (2012).
[61] Henson, Hern, and Snell (2017); White (2018).

can be targeted to students testing at multiple levels of developmental math, though they are sometimes targeted to students who are assessed as having higher-level skills.[62]

Multiple descriptive studies have shown the promise of co-requisite models for improving students completion of college-level math as well as two more rigorous studies.[63] Two rigorous studies have also shown positive effects on students' college course completion. One study employing a rigorous discontinuity design of Austin Peay's redesign found that students in co-requisite courses accumulated more college credits during their first and second years in college than students who were enrolled in traditional developmental courses.[64] A prominent RCT study of a co-requisite redesign at City University of New York (CUNY) found large statistically significant effects on students' completion of a college-level math course and accumulation of credits.[65]

3. Instructional and Content-Based Reforms

In addition to focusing on course sequencing and structure as a means for advancing developmental students' progress, reform efforts have also included revision of the content and pedagogy in developmental (and college-level) math courses. The few studies available of developmental course instruction have shown that instructors often rely heavily on the memorization and procedural application of math facts rather than math concepts.[66] These researchers have shown that this type of instruction can lead students to misunderstand math concepts, and call for instructional models that more clearly connect math concepts, problems, and procedures. [67] Other studies have also found that structured forms of student collaboration and instructional approaches that focus on problem representation may improve math learning and understanding.[68] Finally, some studies have argued that developmental (and college-level) students have more confidence in their math abilities and learning than math instructors may give them credits for, suggesting that faculty may be able to further advance these characteristics in their instruction.[69]

In addition to revising pedagogy, other math leaders have pointed to the disconnect between the content in developmental and college-level mathematics that students are required to learn and their intended careers. Developmental math courses have traditionally focused on algebra content in order to prepare students to take college-level algebra, a requirement for many majors. However, studies have shown that only 22 percent of all workers use simple algebra on the job and only five percent use the higher-level algebra and calculus skills that most college algebra courses teach. Many more careers require basic middle school math and quantitative

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62 Henson, Hern, and Snell (2017).
63 Vandal, 2014; Henson, Hern, and Snell (2017).
64 Boatman (2012).
65 Logue, Wantanbe, and Rose-Douglas (2016).
66 Givvin, Stigler & Thompson (2011); Stigler, Givvin & Thompson (2010).
67 Hiebert & Grouws, 2007; Richland, Stigler, and Holyoak (2012).
68 Hodara (2011)
69 Mesa (2012).

literacy skills, such as the ability to read statistical charts and graphs or work with fractions.[70] As such, these leaders have called for a revision to the math content that students are required to learn, allowing them the option to take math courses such as statistics or quantitative literacy that better align with their intended careers.[71]

Learning communities and cohort-based instruction

A number of colleges have focused on implementing learning communities models, which, in its strongest form, two instructors pair together two courses, have students take these classes as a cohort, and collaborate and build lessons together for both courses. In less intensive versions, courses are just paired together without instructor collaboration. The main effect hoped for from learning communities is that they promote students' social cohesion as well as help them see connections between different academic subjects.[72]

Learning communities models have been used in multiple types of developmental (and non-developmental) courses with students with varying levels of developmental need.[73] Descriptive and quasi-experimental studies on the effects of learning communities in four-year colleges for both college-level and developmental students at over a dozen institutions have found a significant relationship between students' participation in a learning community and their level of engagement with their classes, fellow students, and faculty. Additionally, students participating in learning communities were found to persist to the following year at significantly higher rates than comparison groups who did not participate, even when controlling for differences in students' background characteristics.[74]

RCT studies of learning communities found that they tended to have less robust effects on students outcomes. For instance, RCTs of two learning communities models for developmental math students at Queensborough Community College and at Houston Community College, respectively, found that students in learning communities attempted and passed their developmental math courses at higher rates and progressed more rapidly through their developmental courses sequences than students enrolled in traditional (non-paired) developmental math courses.[75] However, the programs had more modest effects on math credits earned and total credits earned and no impacts on student persistence.[76] Despite this, a more recent regression discontinuity study of students enrolled in learning communities for STEM courses found that the program increased students' academic outcomes and feeling of belonging in college.[77] An RCT study currently under review also shows that learning communities positively affected students' psychosocial outcomes.[78]

[70] Handel (2010); Smith (1999); Hoyles, Noss, and Pozzi (2001).
[71] Charles A. Dana Center (2014); Strother, Campen, and Grunow (2013).
[72] Tinto (1975, 1987); Visher, Schneider, Wathington, and Collado (2010).
[73] Visher, Weiss, Weissman, Rudd, and Wathington (2012).
[74] Engstrom and Tinto (2008); Tinto (1997); Zhao and Kuh (2004).
[75] Weissman, Butcher, Schneider, Teres, Collado, and Greenberg (2011).
[76] Visher et al (2012).
[77] Xu, Solanki, McPartlan, and Sato (2018).
[78] Melguizo, Martorell, Chi, Park, and Kezar (Under Review).

Self-paced instruction and modularization of developmental math course content

Another approach college math practitioners are trying is modularization of developmental math, in which a traditional semester-long or multi-semester sequence of developmental math courses are broken into smaller modules focused around a specific skill or content area. The original intent of these courses was that they would allow students to accelerate their progress through developmental math as they only had to take those modules that they needed to strengthen their skills.

Often modularized courses are offered along with three other developmental reforms. First, students placed into modularized courses often begin by taking a diagnostic assessment that identifies their skill strengths and weaknesses. Students are generally then assigned to take the specific modules they need to strengthen their challenge areas. Second, modularized courses are generally implemented using online or computerized-based math package, such as ALEKS, a computer-based tutorial developed by McGraw-Hill.[79] Others have provided contextualized math content within specific academic domains, such as The Math You Need When Need It.[80] Third, modularized courses are often self-paced, meaning that students are working on their own to complete these modules, often online or in a computer lab with a teacher-facilitator. Students in these self-paced formats also choose how quickly (or slowly) they advance through the modules that they need to complete.

Modularized courses are relatively popular. At least two states (Virginia and North Carolina) redesigned their community colleges' developmental course offerings such that they could only offer modularized courses.[81] Three other states currently encourage colleges to use these courses among other developmental courses supports or reforms.[82] In 2016, 40% of public two-year colleges offered self-paced courses (which often used modularized formats) in developmental math.[83]

Despite this, research on the implementation of technology-based instructional models such as those that self-paced, modularized courses depend on sound a note of caution. For instance, studies have suggested that technology-based instruction can create challenges for both learners and instructors, particularly if either party is not technologically savvy.[84] A number of studies have also shown negative results with online or technology-based learning in colleges when compared with traditional classroom instruction.[85] These results have lead researchers to argue that careful attention needs to be paid to the quality of the interactions between students and instructors.[86] Additional research has shown that more, regular and constructive interactions

[79] McGraw Hill (2019).
[80] Wenner and Baer (2019).
[81] Kalmarkian, Raufman, and Edgecombe. (2015).
[82] ECS (2018). States: FL, ID, WV.
[83] Zachry Rutschow and Mayer (2018).
[84] Natow, Reddy, and Grnt (2017).
[85] Xu and Jaggars (2011); Xu and Jaggars (2013); Fay (2017); Baker, Dee, Evans, and John (2018).
[86] Xu and Jaggers (2013)

between students and instructors can lead to students feeling more committed to a course and achieving better student grades.[87]

The research on modularization has not been as promising, however, in terms of its effects on advancing students more quickly through developmental and college-level math. Though some descriptive studies have shown that modularized courses can improve students' success in developmental and college-level math,[88] others have found that they may slow students' progress. For instance, descriptive studies of Virginia and North Carolina's modularized developmental math sequences found that students tended to progress at a slower pace than in traditional courses. As such, large numbers of students did not complete their developmental and college-level math courses within one year, as was hoped.[89] Similar findings were seen in both descriptive and quasi-experimental studies of modularized math courses in Tennessee's community colleges.[90] Similar findings have been seen in an RCT study in Texas. While students were able to accumulate more developmental credits, students did not complete developmental or college-level math courses at higher rates.[91]

Multiple math pathways

With studies revealing that many careers call for stronger statistical and quantitative literacy skills, many math leaders have begun to call for and implement multiple math pathways. Multiple math pathways focus on diversifying the traditional algebra-for-all math content into different math course tracks that better align with students intended careers. Often, these pathways are focused around three core math subjects, including quantitative literacy for humanities majors; statistics for social and health sciences majors; and calculus pathways for students majoring in science, technology, engineering, or mathematics.[92] Often, math pathways models suggest that multiple math pathways begin with revised content at the developmental level, with students having the opportunity to take developmental courses that integrate more statistics and quantitative literacy content.[93] Several models have also integrated these reforms with an accelerated developmental math course and focus on having students who placed in developmental math complete a college-level math course in one year.[94] Two math pathways models (Carnegie Math Pathways, including Statway and Quantway, and the Dana Center Mathematics Pathways) have also focused on implementing structural reforms, such as accelerated developmental math courses, and pedagogical reforms (such as contextualized, active-learning based instructional models) into the math pathways courses.

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[87] Jaggars and Xu (2016).
[88] Squires, Faulkner, & Hite (2009); Ariovich & Walker (2014); Fay (2017)
[89] Bickerstaff, Fay and Trimble (2016); Kalamarkian, Raufman, and Edgecombe (2015).
[90] Fay (2017); Boatman (2012).
[91] Weiss and Headlam (2018)
[92] Charles A. Dana Center (2019); Carnegie Math Pathways (2019a).
[93] https://carnegiemathpathways.org/; Burdman, Booth, Thorn, Bahr, McNaughtan, and Jackson (2018); Charles A. Dana Center (2014).
[94] Logue, Wantabe, and Rose-Douglas (2016); Zachry Rutschow and Diamond (2015); Carnegie Math Pathways (2019b).

Some math pathways models, particularly those with accelerated developmental math courses, have targeted students in higher-level mathematics courses, though many are also open to students placed in multiple levels of developmental mathematics.[95] However, in order to successfully scale these models to reach larger groups of students, colleges and states must often attend to multiple state and college policies, such as revising the math requirements for certain majors, the alignment of math requirements across two-year and four-year colleges, and advising of students.[96] Despite these challenges, math pathways models have become a popular reform throughout the country, with 41 percent of public two-year colleges now offering these courses to their students.[97]

Several studies have estimated the effects of multiple math pathways on students' success, with two utilizing methodologies. A research study of the Carnegie Math Pathways utilizing propensity score matching found large effects on math pathways students completion of a college-level math course and accumulation of credits.[98] An RCT study of math pathways at CUNY found strong effects on students complete of a college-level math course and accumulation of credits.[99] Additionally, an ongoing RCT study of the Dana Center Mathematics Pathways has found promising effects on an early cohort of math pathways students' completion of college-level math.[100]

Emerging consensus on features of high quality instruction in math

In addition to changing course content, a number of developmental math reforms are aimed at revising the pedagogy and has been integrated into a number of developmental reforms across the country. Overall, pedagogical reforms have emphasized building students' conceptual understanding of math (as opposed to the traditional focus on rote memorization and the application of procedures).[101] Similarly, leaders have called for math learning to be contextualized within real-life situations so that students can better understand how math can be applied in practical life. Many have also called for more student-centered, active-learning approaches that have students play a key role in actively problem solving and working with other students to devise and share solution methods to math problems. Professional math leaders and organizations have also begun to call for these instructional reforms in both developmental and college-level math courses.[102]

These pedagogical tenets underlie a number of curricular and instructional practices embedded within developmental math reforms. For instance, both the Carnegie Math Pathways and the Dana Center Mathematical Pathways have developed curricular models that interweave

[95] Zachry Rutschow and Diamond (2015);
[96] Bickerstaff, Chavarin, and Raufman. (2018); Zachry Rutschow and Diamond (2014);
[97] Zachry Rutschow and Mayer (2018).
[98] Yamada and Bryk (2016); Yamada, Bohannon, and Grunow (2016)
[99] Logue, Wantanbe-Rose, and Douglas (2016)
[100] Zachry Rutschow (2018); Zachry Rutschow, Diamond, and Serna-Wallender (2017).
[101] Mesa, Celis, and Lande (2014); Carpenter, Frank, and Levy (2003).
[102] American Mathematical Association of Two-Year Colleges (2018); Saxe and Brady (2015).

these principles into math instruction.[103] Additionally, CUNY Start, a comprehensive developmental reform aimed at increasing the college readiness of students with multiple developmental needs (discussed more below), focuses on deep conceptual learning and applying math skills within real-life situations.[104] Contextualized and active learning models have also been integrated into numerous basic skills math classes in both workforce development and adult basic education as an effort to promote students' engagement and success.[105]

Research studies have also shown promising results from these types of instructional models. For instance, descriptive studies of developmental math using contextualized instructional models found that students in the first two years of the study earned better math scores and were more likely to find the math instruction they received useful.[106] Quasi-experimental designs of programs such as Washington state's Integrated Basic Education and Skills Training (IBEST) program revealed increases in students' earn college credits and attainment of occupational certificates; recent RCT studies of models similar to IBEST have also shown promising increases in students' academic and labor market outcomes.[107]

4. Support Reforms

A number of reforms to developmental courses aimed at increasing students' progress and success have focused on improving the supports that students receive in these courses. A number of studies have documented the challenges that students in developmental courses may have, ranging from an unfamiliarity with college expectations to a lack of strong social supports among their peers.[108] As a result, many colleges have looked towards improving the supports that students receive within and outside of their math courses as a way to improve students' success.

Success courses

Many colleges have focused on implementing student success courses or new student orientation courses in an effort to improve student success. Also called "study skills" or "student development" courses, these classes may be offered as a stand-alone course or paired with a developmental math course. These courses often vary in length, the number of credits, and content they provide, with some offered as supplemental workshops, and others as full-semester courses. However, they are generally offered for developmental or college-level credit and thus are covered by students' tuition and financial aid. College instructors use number of curricula

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[103] Carnegie Math Pathways (2019b); Charles A. Dana Center (2013)
[104] Scrivener, Gupta, Wiess, Cohen, Cormier, and Brathwaite (2018).
[105] Zachry (2008); Patrick Henry Community College (2019); Jenkins et al (2009); Wright State University (2019).
[106] Shore, Shore, and Boggs. (2004).
[107] Glosser, Martinson, Cho, and Gardiner (2018); Martin and Broadus (2013).
[108] Adelman (2004); Attewell, Lavin, Domina, and Levey (2006); Goldrick-Rab (2007).

and textbooks to lead these courses, many of which focus on developing skills such as students' self-knowledge, awareness of campus services, or study skills.[109]

Student success courses can target students with multiple developmental course needs and are highly common in two year and four-year colleges. For instance, a 2009 survey of 1,000 two-year and four-year institutions found that 87% of two-year and four-year colleges offered student success courses.[110] A slightly more recent survey found that of 288 community colleges, 83% had implemented such courses.[111]

Overall, the research related to the effects of student success courses on student outcomes is mixed. A quasi-experimental study of student success courses in Florida community colleges found that enrollment in these courses was associated with greater likelihood of earning a credential, staying in school, and transferring to Florida's four-year colleges.[112] A number of studies have found positive short-term outcomes on credit accumulation, grades, and persistence.[113] However, longer term studies have shown that these impacts tend to dissipate over time.[114] One study has suggested that more sustained positive student outcomes may come from students attending success courses for a longer period of time (e.g. two semesters) that integrate more student-centered approaches with course content.[115]

Tutoring and supplemental instruction

Tutoring is a popular support that has been implemented by a number of colleges as a means to advance developmental education students' achievement. Like many other student support practices, tutoring can take diverse forms. Tutoring can be offered by faculty, staff, or student peers or through computer-assisted instruction with tutorial software packages. Students may receive individualized assistance or may work in small groups with a tutor outside the classroom. On college campuses, tutors may be housed in a stand-alone center or in learning assistance centers, which provide a number of other supports for students' learning. Finally, tutoring can be either generalized and cover a number of academic subjects or more specialized and focus on a specific curriculum or content area.[116]

One of the more focused models of tutoring is supplemental instruction. Unlike the more generalized tutoring practices that are independent of students' courses, supplemental instruction is a structured tutoring model that is directly connected to a particular course. Generally, a trained tutor or the instructor conducts an additional course section that provides structured

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[109] Zeidenberg, Jenkins, and Calcagno (2007); Zachry Rutschow, Cullinan, and Welbeck (2012); Scrivener, Sommo, and Collado (2009)

[110] Padgett & Keup (2011).

[111] Center for Community College Student Engagement (2012).

[112] Zeidenberg et al (2007).

[113] Boudreau & Kromrey (1994); Schnell & Doetkott (2003); Scrivener, Sommo, & Collado (2009); Strumpf & Hunt (1993); Weiss, Brock, Sommo, Rudd, & Turner (2011); Yamasaki (2010); Cho & Karp (2012).

[114] Boudreau & Kromrey (1994); Zachry Rutschow, Cullinan, & Welbeck (2012); Weiss et al. (2011).

[115] Karp, Raufman, Efhimiou, and Ritze (2017).

[116] Brock, Jenkins, Ellwein, Miller, Gooden, Martin, MacGregor, and Pih. (2007); Perin (2004); Zachry Rutschow and Schneider (2011).

assistance to students about the course material or assignments. Unlike co-requisite models, which tend to pair a college-level math course with a developmental math course, courses that provide supplemental instruction are generally focused on the content of one course (rather than two). The tutor generally sits in the primary course and thus is able to connect their support with classroom instruction.

Tutoring and supplemental instruction are highly popular reforms. Many colleges have tutoring centers, often geared around specific subjects such as math.[117] Six states encourage their colleges to use supplemental instruction as a method for improving developmental students' success, often in conjunction with co-requisite reforms.[118] Descriptive studies have shown mixed results with the generalized tutoring models, though an experimental study found modest positive effects when tutoring was combined with other supports such as success course and intensive advising.[119] Descriptive studies of supplemental instructional models have shown more positive results such as improved grades, lower course withdrawal rate, higher GPAs, and higher rates of persistence and graduation.[120]

Intensive advising

Advising caseloads at colleges can often be sizable, with hundreds of students assigned to one advisor. This situation can result in limited numbers of students receiving advising, which some developmental education scholars have suggested may negatively impact those in developmental courses.[121] In order to overcome this challenge, colleges have been experimenting with reducing advisors' caseloads and creating more intensive advising systems that allow for multiple interactions with advisors throughout the semester. A more intensive version of this model employs faculty, staff, or other leaders to serve as mentors to students.[122] Such advising may occur in-person or electronically, with some colleges implementing advising models that utilize email or texting to remind students of important milestones or to communicate critical information.[123]

Intensive advising models have often been hard to scale, though new text messaging and email variations are showing more promise for scaling. For instance, a text messaging advising campaign was recently implemented for low-income students in West Virginia colleges that showed promise for increasing credit completion in students' freshman year. [124] Various advising interventions have generally shown positive effects on students' outcomes, with more robust effects in the case of more intensive advising. Descriptive studies of e-advising models have shown increases in student persistence, credits earned, and graduation in Florida, and higher

[117] Scrivener, Sommo, and Collado (2009).
[118] ECS (2018). States: WV, OH, KY, CO, CA, AK
[119] Perin (20054); Scrivener, Sommo, and Collado (2009).
[120] Arendale (1997); Bowles, McCoy, and Bates (2008); Hodges and White (2001); Ogden, Thompson, Russell, and Simons (2003); Ramirez (1997).
[121] Grubb (2001).
[122] Visher, Butcher, and Cerna (2010).
[123] Castleman and Page (2013); Zachry Rutschow and Schneider (2011)
[124] Castleman and Meyer (2016).

grade point averages among students in Virginia. [125] Studies of light touch interventions, such as advising whereby students meet with advisors four times over the course of the year, have shown modest short term effects on student persistence and credit accumulation, but did not persist over time.[126] On the other hand, rigorous studies of more intensive models, such as mentoring or coaching, revealed more long-term effects on students' persistence.[127]

5. Comprehensive Reforms

As research on more individualized reforms to developmental education has been published, some reform efforts have begun to focus on how the integration of multiple reforms may affect student success. As noted above, many assessment, structural, instructional, and student supports interventions have been implemented in combination with one another. However, more recently, colleges have begun to focus on more integrated and often longer-term models that provide supports to students throughout their college career. These reforms often focus on students' success in developmental or college-level math (and other developmental and gateway courses) as one step in a series of milestones that lead towards students' successful completion of a degree. As a result, these reforms integrate supports such as intensive advising, accelerated developmental education, financial assistance, and more structured pathways toward completion, which are often provided to students throughout their college career.

Two of the most well-known comprehensive interventions for students with developmental course needs are guided pathways and CUNY's Accelerated Study in Associates Programs (ASAP). Guided pathways focus on four main practices: (1) creating clear pathways for every college program, which allow students to easily map the courses they need to take for completion; (2) providing advising and support models that help students explore and decide on academic plans, including accelerated developmental courses that help them enroll in college-level courses more quickly; (3) instituting advising and alert models that help students know if and when they get off track; and (4) designing programs around a consistent and coherent set of learning outcomes that will allow them to succeed in their future educational and workforce goals.[128]

Another comprehensive support program is CUNY's ASAP that provides comprehensive supports to students throughout their college pathway. The program provides comprehensive advising, career counseling, and tutoring that help students choose and stay on an academic pathway. Additionally, students receive other popular supports such as paired courses that students take as a cohort; a student study skills course; and tuition waivers that covers any gap between students financial aid and financial need. Finally, the CUNY ASAP program requires students to enroll in college full-time and finish their developmental course work early.[129]

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[125] Shugart & Romano (2006); Herndon (2011).
[126] Scrivener & Weiss (2009).
[127] Bettinger & Baker (2011).
[128] Bailey, Jaggars, and Jenkins (2015).
[129] Scrivener, Weiss, Ratledge, Rudd, Sommo, and Fresques (2015).

A new community college in the CUNY system, Guttman Community College, has also integrated many of the recommendations in the guided pathways and ASAP models. For instance, all students are full-time and progress together as a cohort; declare a major in their 2nd semester from a limited set of degrees to choose from that are aligned with local industry needs; and students meet regularly with advisors and mentors.[130]

A more short-term comprehensive reform, CUNY Start, focuses on advancing the skills of students with multiple remedial needs in one semester. CUNY Start includes promising instructional reforms such as active learning and contextualized instruction; provides full-time (24 hours a week) or part-time (12 hours a week) instruction in reading, writing, and math; and has students take courses as a cohort throughout the semester. Services are provided to students before they matriculate into college, thus preserving their financial aid for credit-bearing courses rather than towards skills building through developmental courses.[131]

While the CUNY ASAP and CUNY Start programs have been relatively limited in scale, guided pathways have become a movement in many community colleges throughout the U.S. Recent estimates noted that guided pathways were being implemented in at least 250 colleges and at least ten states.[132] This implementation has also been promoted by important college associations such as the American Association of Community College's Pathways Project and Complete College America's promotion of Guided Pathways to Success.[133]

Research on comprehensive reforms provides some of the most promising evidence on improving students' success in mathematics and English. Descriptive research of guided pathways suggests that students in these types of comprehensive reforms earn more credits more quickly in their first academic year and had higher completion rates in college math and English relative to students in colleges before guided pathways were implemented; however, there were also slight decreases in student persistence and overall college credit pass rates.[134] Early findings from an RCT study of CUNY Start also show promising results, with students in the program making substantially more progress through developmental courses, especially developmental math, and having higher enrollment rates.[135]

CUNY ASAP shows some of the most striking results on students' success. This combination of comprehensive supports substantially improved students' academic outcomes and nearly doubled the graduation rates of students within three years. Students in the CUNY ASAP program earned substantially more academic credits and 40 percent of these students had completed an associate's degree in three years, compared to 25 percent of those in the control group.[136] Recent research has shown similar results in Ohio, with 40 percent of ASAP students graduating in a three-year period compared to 23 percent of students in the control group.[137]

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[130] Bailey, 2015.
[131] Scrivener et al (2018).
[132] Bailey (2017).
[133] Complete College America (2017).
[134] Jenkins, Brown, Fink, Lahr, and Yanaguira (2018)
[135] Scrivener et al (2018).
[136] Scrivener et al (2018).
[137] Sommo, Cullinan, and Manno (2018).

Summary

Highly supported in the narrative above, colleges have been extremely active in the last decade, exploring new ways to improve the progress and success of students taking developmental courses. The most promising of these reforms integrate multiple strategies, including advising, financial assistance, pathway models, and acceleration, one of which has had a substantial impact on students' graduation rates. More specifically, the results of the CUNY ASAP model show some of the strongest positive effects on developmental students' outcomes to date. In comparison, other reforms show more modest, but still positive, impacts on helping students' progress through their developmental and first college-level math courses. In particular, math pathways and co-requisite models seem to hold a good deal of promise for helping students more quickly complete these courses.

Interestingly (though perhaps not surprisingly), the scaling of developmental math reforms is not always related to rigorous evidence of their effectiveness. For instance, there have been few rigorous research studies of some of the most popular and highly scaled reforms, such as co-requisite models, success courses, and guided pathways. Additionally, some reforms that are highly scaled, such as compressed courses and success courses, show mixed results. This is not unusual, as many practitioners and policymakers have argued that more rigorous studies of developmental reforms takes too long and the urgency around students' poor success rates in developmental courses requires more urgent action.[138] However, it does reveal that in the need to act quickly, some colleges may not be implementing reforms that have the greatest chance for helping students' succeed.

Moreover, despite many studies demonstrating the promise of developmental education reforms, the overwhelming majority of public colleges in the U.S. continue to use multi-semester, prerequisite developmental course sequences.[139] For instance, a nationally representative survey of public two-year and four-year colleges in 2015-2016 found that 76% and 53% of public two-year colleges continued to implement multi-semester, pre-requisite sequences to their students.[140] This suggests two things. First, it reveals that though many colleges may be implementing developmental reforms, they are doing these alongside, rather than in place of, longer developmental course sequences. Additionally, juxtaposing these numbers against the lower percentages implementing new reforms suggests that many community colleges may implementing very few to no reforms to developmental math and continuing with their standard course sequences. An upcoming report in 2019, which will discuss the number and scale of these reforms across two-year and four-year colleges, will shed more light on this issue.

In most cases, success in developmental math reform has often meant helping students successfully complete their first college-level math course. Much of this focus has been based

[138] Zachry Rutschow and Schneider (2011).
[139] Zachry Rutchow and Mayer (2018).
[140] Zachry Rutchow and Mayer (2018).

This paper was commissioned for the Workshop on Understanding Success and Failure of Students in Developmental Mathematics. The workshop was convened by the Board on Science Education on March 18 – 19, 2019 in Washington, DC with support from Ascedium Education Group (the Great Lakes Foundation). Opinions and statements included in the paper are solely those of the individual author, and are not necessarily adopted, endorsed, or verified as accurate by the Board on Science Education or the National Academy of Sciences, Engineering, and Medicine.

on the fact that math is a key stumbling block to students' completion of college.[141] Far less emphasis has been put on attracting students to math and math-focused careers, though this is the subtext in many of the instructional reforms that aim to improve students' engagement and enjoyment of math learning.[142] This may be because very few studies of postsecondary education have looked at specific learning outcomes from math courses and how different instructional models might best promote this learning.[143] This area represents an important new frontier for further research into postsecondary math education.

New research studies are set to be released in the next year which will provide more information on the scale and impact of new developmental math reforms. For instance, the Center for the Analysis of Postsecondary Readiness will release a final report on the most recent nationally representative survey of two-year and four-year college practices in developmental education, including an analysis of the scope and scale of reforms to assessment, placement, instruction, and student supports.[144] Additionally, final reports are scheduled to be released on the use of multiple measures assessment in New York's SUNY system and on the Dana Center Mathematics Pathways.[145]

Despite the promising efforts described in this paper, critical challenges remain in developmental education. For instance, as an approach to improve students' success, many colleges have reduced or eliminated their developmental course offerings, particularly for students whose assessment results suggest lower-level skills in math. [146] This reduction in services, and particularly in the case of lower level developmental math courses, is reasonable given research showing that little good comes from enrolling students in multiple levels of developmental math. [147] However, this may also mean that many students who originally entered college with an opportunity to improve their skills may not have respective services available to them—or those services may be much harder to access than they were previously, as colleges turn to other agencies (such as adult basic education or workforce development) for help. Many are already raising questions about what this means for community colleges and other open access institutions with traditional open-door policies.[148]

Another challenge for colleges is likely the cost of these interventions. While cost effectiveness studies of comprehensive reforms like CUNY ASAP suggest that they are cost effective relative to their graduation rate impacts, CUNY ASAP both in New York and in its slightly revised form in Ohio cost thousands of dollars per student to implement.[149] This price tag likely looks daunting to many colleges regardless of its effectiveness. Other reforms such as intensive advising or multiple math pathways cost less, but still require multiple resources to

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[141] Charles A. Dana Center (2014).
[142] Strother, S., Van Campen, J., and Grunow, A. (2013)
[143] Barr and Tagg (1995).
[144] Zachry Rutshcow and Mayer (2018).
[145] Barnett et al (2018); Zachry Rutschow (2018).
[146] Visher et al (2017).
[147] Xu and Dadgar (2017)
[148] Visher et al (2017)
[149] Sommo et al (2018); Scrivener et al (2015).

implement—not to mention the time needed to hire and train faculty and staff.[150] The need for such resources likely makes other less intensive—and less costly— reforms, such as course compression, look more attractive. Finding ways to help colleges overcome the initial sticker shock with some developmental reforms will likely be an important area of focus.

These challenges, along with goals to move beyond a focus on passing college math and instead engaging students in math content, remain the next frontier for postsecondary education research. The promising results of the many evaluations of new math interventions reveal that colleges may well be able to push these students towards this end. However, in order to do this, there likely needs to be a more concerted effort to bring together multiple aspects of these developmental and college-level math reforms, rather than the somewhat haphazard implementation that has occurred thus far. Multiple measures of assessment may improve an understanding of students' college readiness and placement into the correct courses while acceleration through co-requisite courses shows promise at advancing students more quickly through their developmental courses when they are placed there. Similarly, multiple math pathways show promise in realigning math to specific career areas while more engaging and contextualized instructional models may be helping students become more interested in math learning. Finally, providing strong supports for students' academic and social progress in college is also important. However, in many cases, this full suite of interventions is not being implemented together in a comprehensive package aimed at math instruction.

Some states and initiatives show how these types of reforms can be combined to promote more comprehensive approach to math success. For instance, Texas has recently implemented multiple developmental math (and English) reforms that require or strongly encourage colleges to use multiple measures assessment, multiple math pathways, compression of developmental courses, and co-requisite courses.[151] Similarly several highly scaled math pathways interventions incorporate more promising instructional methods along developmental math acceleration and revision of math content.[152] Finding ways to further promote this type of integration may go far in helping colleges further advance students' math skills and interest—and hopefully bring more students into the science, technology, engineering, and mathematics careers where they are so needed.

[150] Scrivener et al (2009); Zachry Rutschow and Diamond (2015).
[151] Daugherty, Gomez, Gehlhaus, Mendoza-Graf, and Miller (2018).
[152] Carnegie Math Pathways (2019b); Charles A. Dana Center (2013)

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Appendix Table 1.
Developmental Math Reforms and Summary of Research on the Effectiveness at Increasing Students' Math and College Success

Type of reform	Description	Highest level(s) of evidence found	Research on effectiveness
Assessment and placement reforms			
Multiple measures assessment	Multiple measures of students' skills and college-readiness are used together to make decisions about developmental or college-level course placement	Quasi-experimental; experimental	Students more likely to be placed in college-level courses and more likely to enroll in college level courses.
Diagnostic assessment	Fine grained assessments used to "diagnose" students' skill strengths and challenges. Often used in conjunction with self-paced or modularized courses.	Quasi-experimental	Diagnostic assessments more effective at assessing college readiness than computer adaptive assessments.
Early assessment and transition programs	Students' college readiness is assessed in high school, and students are afforded the opportunity to build their skills while still in high school.	Quasi-experimental	Higher placement into college-level math courses; generally few differences in completion of college-level math
Reforms to developmental course structure			
Bridge courses and non-course based options for skill building	Shorter-term skill building sessions either before the semester starts (often called summer bridge programs) or through non-course based options during the school semester (such as working to build skills through a technology-based program)	Quasi-experimental; experimental	Positive effects on graduation rates at four-year colleges; no effects in two-year colleges

Compression of developmental math courses	Compressing the course content from two semester-long courses into one semester	Quasi-experimental	Positive effects on college-level math completion
Co-requisite models	Enrollment of students assessed with developmental needs directly into college-level courses with a supplemental support course or support services (such as tutoring)	Quasi-experimental; experimental	Large effects on completion of college-level math and accumulation of credits
Instructional and content-based reforms			
Learning communities and cohort based models	The pairing of two or more courses that students take together as a cohort. In stronger models, teachers also collaborate and additional student supports are provided.	Quasi-experimental; experimental	Positive effects on completion of developmental math; mixed on other academic outcomes; positive effects on psychosocial outcomes
Self-paced instruction and modularization of developmental math course content	Breaking down semester-long courses into shorter modules, with students taking only those modules that they need to build skills. Often self-paced either online or in a computer lab with a teacher facilitator.	Quasi-experimental; experimental	Are there no findings for this type of reform to highlight? If not, can you include a statement here that explains this?
Multiple math pathways	Diversification of math requirements based students' intended career or major. Three common pathways are quantiative literacy for humanities majors; statistics for social sciences majors; and calculus for STEM majors	Quasi-experimental; experimental	Positive effects on completion of developmental and college-level math; positive effects on credit accumulation
Features of quality math instruction	Efforts to revise traditional lecture-based instruction to incorporate more student-centered, active learning pedagogies, student-led problem-solving, and the contextualization of math in real-life situations, among other attributes.	Quasi-experimental; experimental (instruction strategies are often incoporated	Are there no findings for this type of reform to highlight? If not, can you include a statement here that explains this?

		with other reforms)	
Support reforms			
Success courses	A study skills or student orientation course that helps build students' awareness of college expectations and/or explore career interests	Quasi-experimental; experimnetal	Mixed - quasi-experimental showed positive effects on persistence, completion, and transfer to 4-year colleges; experimental show short-term impacts on persistence and credit accumulation that dissipate over time
Tutoring and supplemental instruction	Extra academic help provided either in a lab or center (tutoring) or as an attachment to a particular math class (supplemental instruction)	Experimental	Modest positive effects on credit accumulation and persistence (in conjunction with a success course and intensive advising)
Intensive advising	A reduction in advisors caseloads such that they can meet with students more frequently (e.g. multiple times in a semester). May be paired with email, text, or phone advising that informs students about important milestones	Experimental	Modest positive effects on credit accumulation and persistence (in conjunction with a success course and tutoring)
Comprehensive reforms			

Guided pathways	A coordinated set of reforms that (1) encourages students to complete developmental math requirements early, (2) provides clearer guidance on academic pathways, early alert and advising models that help students stay on track, and (3) designs learning outcomes and goals to match with future education and workforce goals.	Descriptive	More credits earned, higher completion of college level math and English, slight decreases in persistence and course pass rates
CUNY ASAP	Coordinated set of reforms throughout students' college career, including requirements to enroll full-time, intensive advising, career counseling, tutoring, paired courses taken as a cohort, tuition waivers, success course, and requirements to finish dev ed early in college career	Experimental	Large positive effects on developmental and college-level course completion; persistence; credits earned; and graduation
CUNY Start	Comprehensive reform for students with multiple developmental needs in reading, writing, and math, including promising instruction reforms; paired courses that students take as a cohort; intensive or part-time instruction using promising instructional methods such as contextualization and active learning; and tuition free	Experimental	Positive effects on progress through developmental courses and enrollment