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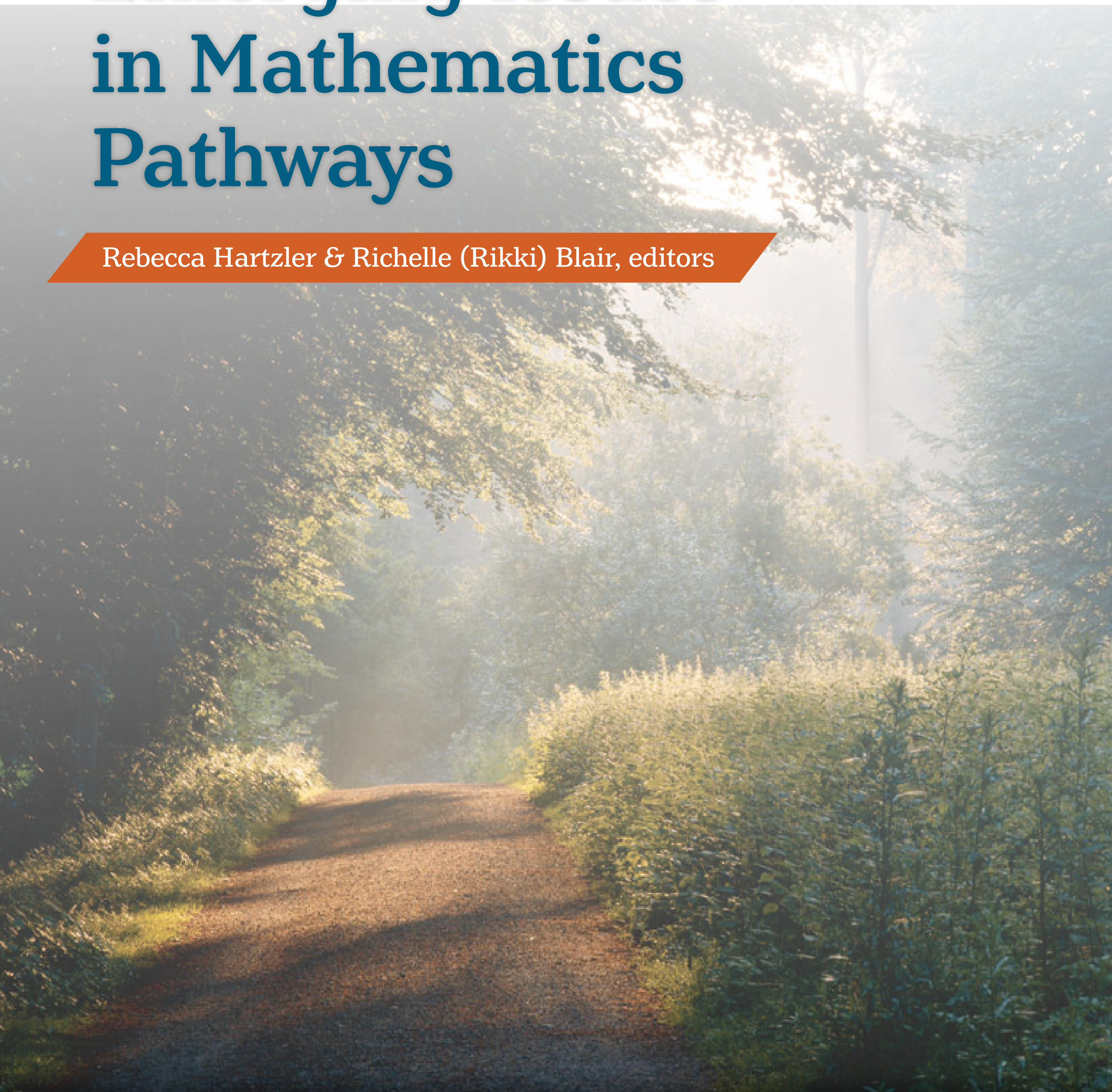
Emerging Issues in Mathematics Pathways

Rebecca Hartzler & Richelle (Rikki) Blair, editors



Case Studies, Scans of the Field, and Recommendations

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About the Charles A. Dana Center at The University of Texas at Austin

The Dana Center develops and scales education innovations to support educators, administrators, and policymakers in creating seamless transitions throughout the K–14 system for all students, especially those who have historically been underserved. We focus in particular on strategies for improving student engagement, motivation, persistence, and achievement.

We help local systems adapt promising research to meet their needs, and we develop innovative resources and tools that are implemented through multiple channels, from the highly local and personal to the regional and national. We provide long-term technical assistance, collaborate with partners at all levels of the education system, and advise community colleges and states.

The Center was founded in 1991 at The University of Texas at Austin. Our staff members have expertise in leadership, literacy, research, program evaluation, mathematics and science education, policy and systemic reform, and services to high-need populations. We have worked with states and education systems throughout Texas and across the country. For more information about our programs and resources, see **www.utdanacenter.org**.

About the Dana Center Mathematics Pathways (DCMP)

The Dana Center Mathematics Pathways (DCMP) is a systemic approach to dramatically increasing the number of students who complete math coursework aligned with their chosen program of study and who successfully achieve their postsecondary goals. The DCMP was initially launched as the New Mathways Project (NMP) in 2012 through a joint enterprise with the Texas Association of Community Colleges. For more information about the DCMP, see www.dcmathpathways.org.

Acknowledgments

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Ophella Dano, project editor

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Nancy Kennedy, writing coach (Edmonds Community College)

Amanda Laughtland, copyeditor (Edmonds Community College)

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Preface

In the past decade, the phrase *mathematics pathways* has taken on a very specific meaning in higher education. Mathematics pathways are minimally thought to be the required mathematics courses or sequences of courses that support a student's program of study. Over time, mathematics pathways has become known as a national effort to redesign the structures of postsecondary mathematics instruction to greatly improve student success and eliminate mathematics as the barrier to completion that it became in the last century.

While there are many models of mathematics pathways, they all restructure lower division mathematics in two important ways: (1) teach only the mathematics that are relevant to students' programs of study, and (2) significantly reduce or eliminate the number of non-credit mathematics courses that students are required to take before being allowed to enroll in college-level mathematics courses. The data show that restructuring towards a small set (3-5) of accelerated mathematics pathways can increase student success in the first college-level mathematics course from 20 percent in the traditional developmental sequences to 60 percent or more, and in far less time (sometimes saving over a year's time) and at far less cost to students (saving the tuition of two or three courses).

Over the past decade, three mathematics pathways have emerged, which have been adopted by most institutions: (1) quantitative reasoning, (2) statistical reasoning, and (3) the pathway to calculus or STEM pathway.

There are many mathematics pathways initiatives across the United States. The work of the Dana Center Mathematics Pathways (DCMP) focuses on systems change including curriculum design, professional development, advising, institutional research, institutional and state policy alignment, and national advocacy.

The DCMP vision is to ensure that all students in the U.S. have equitable access to and the opportunity for success in rigorous mathematics pathways that are aligned and relevant to their future aspirations, propelling them to upward economic and social mobility. The DCMP model relies on four principles that guide the work with stakeholders and institutions across a state to implement structural and policy changes so that (1) all students, regardless of college readiness, enter directly into mathematics pathways aligned to their programs of study, and (2) students complete their first college-level math requirement in the first year of college.

Next, institutions and departments engage in a process of continuous improvement to ensure high-quality instruction. Students engage in a learning experience that is designed so that (3) strategies to support students as learners are integrated into courses and aligned across the institution, and (4) instruction incorporates evidence-based curriculum and pedagogy. The DCMP supports state efforts to establish mathematics pathways as normative practice by working at all levels of the system, meaning across individual institutions and among all the institutions in the state.

While mathematics pathways are not new, there is still a long way to go towards wide-scale adoption and normative practice. The premise of this monograph is that there is expertise to be shared and issues still to be addressed. The authors were brought to Austin, Texas, in August 2017 for a writing workshop where they were given time to research, think, write, and work with the editors and a writing coach. After the workshop, authors spent the following months completing and refining drafts, and working with the editors toward the final product.

The monograph comprises chapters organized along topics that are aligned with the DCMP theory of change. The DCMP believes that systemic and sustainable change is best achieved through a process that is *faculty-driven, administrator-supported, policy-enabled, and culturally reinforced*. We hope that each chapter will provide the guidance and inspiration for improving student success in mathematics education through the widespread adoption, implementation, and continuous improvement of mathematics pathways.

To learn more about the DCMP, please visit our resource site at https://www.dcmathpathways.org. To learn more about The Charles A. Dana Center, please visit our website at http://www.utdanacenter.org.

Special thanks

Emerging Issues in Mathematic Pathways: Case Studies, Scans of the Field, and Recommendations was an undertaking that involved organizations and individuals dedicated to higher education and student success. We are very grateful to the authors who contributed their knowledge and firsthand experience in the field, and to our writing coach, Nancy Kennedy, and copyeditor, Amanda Laughtland.

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Rebecca Hartzler, The Charles A. Dana Center at The University of Texas at Austin
Richelle (Rikki) Blair, Dana Center Mathematics Pathways Leadership Fellow; Lakeland Community College

Authors and editors at the writing workshop in August 2017 (left to right): *Back row*: Patricia Parker, Carl Krueger, Francesca Fraga-Leahy, Michael Oehrtman, Jennifer Dorsey, Vanessa Harris, Francisco Savina, Richelle (Rikki) Blair, Jeremy Martin, Stuart Boersma, Heather Ortiz, and DeWayne Morgan. *Middle row*: Ophella Dano, Alycia Marshall, Heather Cook, Lori Austin, Stephanie Hall, and Nancy Stano. *Front row (seated)*: Nancy Kennedy, Rebecca Hartzler, Connie Richardson, and Lucy Michal.

About the editors

Rebecca Hartzler served as the manager for advocacy and professional learning at the Charles A. Dana Center during the creation of this monograph. Rebecca taught physics, mathematics, and engineering at Washington state community colleges for over 25 years, served as a dean for science and mathematics, and designed and directed several federal and privately funded STEM student success projects on state and national levels, including the Carnegie Math Pathways, Achieving the Dream, and the National Science Foundation. She currently works as a program officer for the Postsecondary Success team at the Bill & Melinda Gates Foundation.

Richelle (Rikki) Blair's interests throughout her career have been curriculum development, incorporating innovative strategies into classrooms and improving mathematics experiences for students at two-year colleges, and on designing and implementing mathematics pathways.

As professor of mathematics at Lakeland Community College in Kirtland, Ohio (1981-2001), and former department chairperson, Rikki worked diligently to promote active learning for her students and to bring technology into the curriculum. She is the author of two textbooks, *Introductory Algebra* and *Intermediate Algebra*, for two-year college students. Rikki served as the associate director for two-year colleges of the 2010, 2015, and 2020 CBMS National Surveys of Undergraduate Programs in the United States; as past president of the American Mathematical Association of Two-Year Colleges (AMATYC); and as a mathematics curriculum consultant and a leadership fellow at the Charles A. Dana Center at The University of Texas at Austin.

Section 1

Faculty Leadership and Curriculum Development

Chapter 1

Faculty Engagement for Creating and Sustaining Mathematics Pathways

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Abstract

Redesign initiatives in postsecondary mathematics to provide more students with successful experiences are revitalizing partnerships among two-year and four-year faculty and their institutions and are creating sustainable systemic change. Because achieving research-based educational change occurs foundationally within teaching, faculty engagement is vital to systemic change. This chapter presents processes that sustain faculty engagement: data analysis, identification of problems and solutions, design and implementation of those solutions, evaluation of progress, and understanding of changes accompanying the implementation of mathematics pathways. Also addressed are less obvious but equally critical aspects of faculty engagement, such as early participation in conversations for creating change and communication of the rationale for changes to other stakeholders. Processes common to both two-year faculty and four-year faculty are discussed first, followed by how to foster faculty engagement between institutions.

Introduction

New mathematics pathways and multiple entry-level course options designed to meet the needs of a broader range of degree programs have placed faculty at the front lines of creating lasting systemic change and are revitalizing partnerships between two-year and four-year faculty and institutions.

The implementation of multiple mathematics pathways relevant to different programs of study is now a major strategy in many institutions and has been adopted in over 16 states at the time of this writing. For example, in Texas, all 50 public community colleges are involved in such pathways, as are all 27 public institutions of higher education in Oklahoma. The emergence of mathematics pathways across the country is directly related to the persistent experimentation of individuals and groups of educators who sought to offer mathematics courses that were worthy of their students' goals and time. Those efforts led to broad consensus among mathematical professional organizations that endorse the model of mathematics pathways as worth exploring and supporting. Ongoing efforts to implement and sustain mathematics pathways at scale depend on faculty leadership to establish effective reforms that are systemic and sustainable. In their roles behind the scenes in course development and at the daily front lines of classroom implementation, mathematics faculty have the subject-matter expertise to develop and maintain rigorous and meaningful mathematics courses that serve students' interests. The ongoing effort to implement mathematics pathways around the country will succeed only with strong ownership and engagement of faculty.

In this chapter, the role of faculty in developing and implementing mathematics pathways is examined from the perspectives of both two-year and four-year faculty and their institutions. This chapter presents narrative common to both and offers examples of how faculty engagement can be fostered by the early inclusion of key stakeholders, collecting data, building engagement, supporting ongoing communication, and implementing professional development.

Initial Steps: Early Faculty Engagement and Data Review

Faculty engagement begins with a working team of mathematics faculty and should be formed early in the process. This team should engage in the initial steps of designing and implementing a mathematics pathways program by exploring alternative strategies and seeking input from faculty at other institutions who have wrestled with similar problems. These discussions inform faculty about the reform approaches, details of implementation, what does and does not work, and important steps that might enable positive changes. Many faculty are appropriately skeptical of new approaches and need to be provided with large-scale data demonstrating the effectiveness of mathematics pathways at other institutions and systems, particularly those with similar characteristics as their own. Faculty may also have a tendency to want to pilot small-scale versions of reforms. However, reviewing data that illustrate that students are not being better served by the status quo, or worse—that great numbers are being harmed—creates the urgency to scale as quickly as possible.

The faculty view of student success is nearly always at the course level. From the lecture hall, lab, or office hours, faculty experience course-specific, semester-long snapshots of their students' academic programs and lives. From this perspective, inspiring performances on challenging projects or an 80-percent pass rate in a course are measures of success. However, faculty are often not able to see the number of students who never made it to their courses in the first place. They do not know whether their students continued to the next course nor how they fared once there. Faculty may not know whether their courses were ultimately applicable to completing the students' certificates or degrees. By engaging in data review and program redesign—by listening, planning, implementing, and evaluating new mathematics pathways—faculty can gain a broader perspective and participate in transforming key aspects of academic structures that undermine student success. The selection, collection, and review of institutional data to obtain a broader perspective of the role of mathematics courses in the academic system are critical initial steps in program redesign and faculty engagement. Although faculty may have a strong experiential sense about what currently works well in their courses and departments, close review of student success data is necessary to identify and understand previously overlooked problems.

When disaggregated and explored longitudinally, student data reveal which populations succeed, which do not and, where unforeseen, problematic points occur. Not all data need to be collected at once, and faculty may desire to collect other data once a few sets of data have been collected, analyzed, and processed in conversations. As data are reviewed, the faculty team can clarify possible problems by interviewing strategic groups of people. Typical stakeholder groups include faculty from other disciplines who might offer a different perspective, students who were successful in mathematics and have shifted to a non-STEM major, students who have repeated a particular mathematics course, and advisors who work with struggling students.

Early, Comprehensive, and Ongoing Faculty Conversations

Faculty involvement is key to any curriculum transformation effort (Allan & Estler, 2005; Bailey, Jaggers, & Jenkins, 2015; Niehaus & Williams, 2016). After data analysis is complete, mathematics pathways implementation begins with early and comprehensive conversations among mathematics faculty, faculty in partner disciplines, faculty in neighboring two-year colleges and four-year universities, and faculty across the state or nation with experience in similar reform. Being involved in making crucial decisions during early planning about new mathematics pathways allows faculty to participate in developing solutions. Such discussions are richer when they involve a broad range of faculty, including those teaching current gateway courses, developmental prerequisite courses, and courses in partner disciplines that subsequently use content in gateway courses.

Although faculty may be eager to implement changes on their campus immediately, these structural changes take multiple semesters to employ. That time is best used to foster broad faculty engagement to build understanding and ownership. Members of the working team should document their understanding of the problems to address on their campus, the potential challenges in implementing various strategies, and possible resolutions to these implementation challenges. As specific strategies are identified, the team should develop descriptions of how those changes will be implemented, timelines for action, and who needs to be involved or informed at each stage of the change process.

Early in the planning phase, an inventory of specific mathematical competencies required for programs of study in regional or statewide two-year and four-year institutions should be developed. A complete survey of program requirements for mathematics courses provides a strategic starting point to review mathematical prerequisites and competencies that students need to successfully complete two-year and four-year program degree requirements. In both Texas and Oklahoma, an inventory of program requirements was compiled for all public four-year institutions in each state. This inventory helped mathematics faculty to understand the need to rethink the student learning outcomes of traditional courses and design new courses more relevant to programs of study. Additionally, a survey enables faculty to identify where changes in degree requirements should be considered to ensure that courses taken at one institution will be *applicable* to the students' programs of study when transferred to another institution.

Faculty conversations serve to nurture collaborative planning with others, support instruction, and create aligned assessments for student learning when implementing mathematics pathways. El Paso Community College (EPCC) in Texas successfully implemented mathematics pathways by engaging mathematics faculty in the initial development, review, and offering of statistics pathways courses. At EPCC, involvement in the Guided Pathways program (Jenkins, 2014) allowed the inclusion of all faculty in pathways discussions, boosted implementation of mathematics pathways, and facilitated conversations with faculty from other disciplines. As EPCC's Guided Pathways program evolved, the need to construct groups of common majors (called meta-majors) required faculty to engage in conversations with both Science, Technology, Engineering, and Mathematics (STEM) and non-STEM programs.

In the process of implementing mathematics pathways programs, communication and collaboration between two-year college faculty and four-year college faculty ensures the articulation and applicability of courses to programs of study when students transfer. These partnerships should also involve academic advisors from two-year and four-year institutions who can review and provide feedback on the modified requirements for program-specific mathematics courses.

Re-envisioning Mathematics Prerequisites, Placement, and Competencies

Engaging mathematics faculty early in conversations with other faculty and administrators from other disciplines and institutions provides time for dialogue and discussion around mathematical prerequisites and competencies required in students' broader pursuits. As faculty collaborate with partner institutions, sharing common practices can facilitate needed changes to transfer, prerequisite, and placement policies.

In addition to offering entry-level mathematics courses more appropriate to various degree programs, faculty often encounter related issues that need to be addressed. For example, a typical pass rate (grade of C or better) for developmental and gateway courses is 70 percent. Similarly, the persistence rate (for proceeding to the next course) is also often around 70 percent for such courses, meaning that each course in a required sequence reduces the number of successful students by about half (Tennessee Board of Regents, 2016; Thompson et al., 2007; University System of Georgia, 2013; Wilson & Oehrtman, 2017). Administrators and faculty at many institutions are realizing that the trickle of students emerging from long sequences of courses, especially at the developmental level, is more a result of time and attrition than anything else. Students placed into remedial courses often internalize the message that they are not "college material" and consequently are quick to give up when the courses, or intervening life circumstances, become challenging. Students in College Algebra are often not able to see any meaningful use of the symbolic manipulation they are asked to master and develop a view that succeeding in college is a game that they need to play (Burdman, 2015; Gordon, 2008).

Collaboration among faculty across two-year and four-year institutions and across disciplines can greatly enhance the effectiveness of discussions about relevant and engaging mathematics content. For example, by reviewing longitudinal student success data, faculty nationwide can collaborate to accelerate underprepared students into credit-bearing math courses with remediation provided as additional support that is aimed in a timely and direct way to support success in that course. Likewise, mathematics pathways that are tailored to non-STEM degree programs and incorporate relevant applications and quantitative tools relevant in other fields help students appreciate the relevance of these courses. Such shifts are only possible with significant opportunities for math faculty to review relevant data to make, design, and implement informed decisions.

Degree programs often require a variety of mathematical competencies that are not addressed in a single gateway course or that may not be presented in ways that convey their relevance to students in non-STEM programs of study. Faculty sharing strategically selected lessons from mathematics courses can showcase the competencies students will need before enrolling in a subsequent non-mathematics course. Such collaborations can also help identify core content in each mathematics gateway course that coherently frames and supports significant portions of subsequent courses in students' programs of study. For such topics, faculty should develop:

(i) a description of the levels of understanding desired for all students in the course;

(ii) common entry points for students' understanding;

(iii) a progression of challenges and solutions in which students must engage to develop these understandings;

(iv) common pitfalls in the learning process and ways to address them;

(v) a mapping of ways in which these core concepts support thinking and learning throughout the entire course; and

(vi) applications relevant to the academic degrees supported by the gateway course that could serve as strong context for the learning goals.

Professional Development Focused on Advances in the Learning Sciences

While most faculty have honed their teaching expertise through years of individual practice, reflection, and discussion, few faculty are familiar with new approaches that can be adapted in their courses. As changes are implemented, faculty may become overwhelmed by new curricula pedagogy, assessments, and classroom structures. Support is critical to help faculty adjust to the changes.

A crucial part of a dynamic and growing educational enterprise, faculty development is "a necessity, not a nicety" (McKee & Tew, 2013, p. 3). Faculty development that focuses on advances in teaching and learning via the learning sciences (Bransford, 1999) has already enriched many faculty conversations when implementing mathematics pathways. Professional development to implement mathematics pathways must engage faculty in identifying and understanding student characteristics and core content in mathematics pathways courses. Faculty also need time to learn about teaching and learning processes for these concepts. Important points in these faculty development conversations should be about "knowing how to apply this knowledge" and "applying the discoveries of the learning sciences to teaching in ways that improve and yield meaningful information about student learning" (Moy, 2014, p. 42).

The interactions between students' views of their intelligence and abilities and their persistence and goal orientations are particularly critical for entry-level students (Blackwell, Trzesniewski, & Dweck, 2007; Dweck & Leggett, 1988). Individuals who view intelligence as innate and fixed tend to adopt goals to demonstrate proficiency and persist only in cases of perceived success, while avoiding challenge when they perceive failure. On the other hand, individuals who view intelligence as malleable, and able to grow with use, typically adopt goals to increase their competence and persist, seeking challenges regardless of success. These effects are particularly strong when gender or racial stereotypes of performance are activated in learners (Aronson, 2007), raising particular concerns for the impact that such self-theories may have on performance and persistence of underrepresented populations in academic pursuits. Supporting students' development of a growth mindset requires careful attention to the interplay between mathematical tasks, mathematics as an intellectual pursuit, and the goals, interests, and resources that students bring to the learning environment.

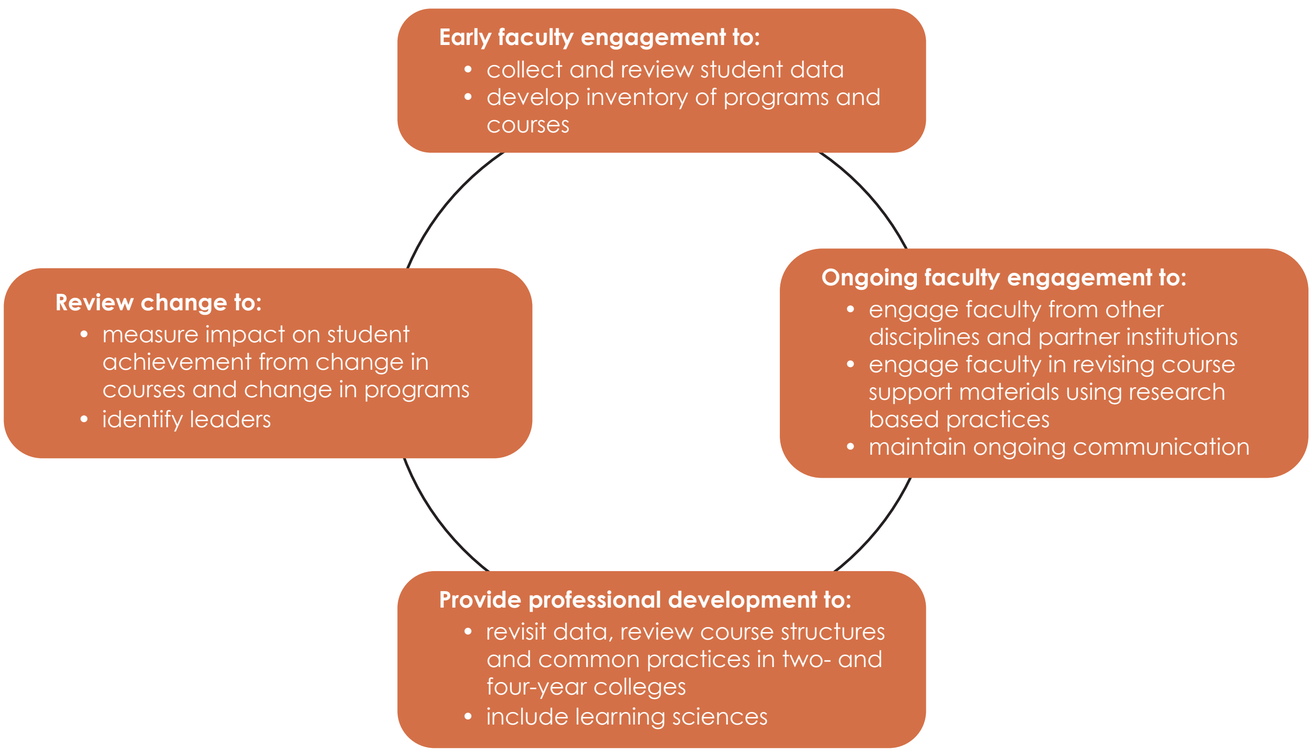
Professional development requires persistence. Faculty development related to implementation of mathematics pathways should not be about attempts to change people but rather about engaging faculty early in focused, ongoing conversations. When data showing increased measures of student success are provided, efforts may be easier to implement, scale, and sustain. As Kegan and Lahey (2001) observed, "Successful collaborative efforts do not occur because leaders change hearts and minds, but rather because they clarify and emphasize how these efforts will promote individuals' preexisting values" (p. 73).

Conclusion

Key recommendations to faculty and institutions considering a curricular redesign are summarized in Figure 1. This cycle of improvement includes:

1) **early engagement of faculty** to collect and review data, courses, and programs of study;
2) **ongoing conversations** with comprehensive groups of faculty from other disciplines and partner institutions;
3) **professional development** to discuss institutional, regional, statewide, and national student data; to identify and clarify mathematical prerequisites and competencies, placement, and common practices in two-year and four-year partners; and to incorporate advances in the learning sciences; and
4) **review of the impact that change has on student achievement** and identification of leadership to continue faculty engagement.

Figure 1. Continuous cycle for engaging faculty in program redesign and implementation



Effecting long-term change at the scale of multiple academic institutions, or even an entire state, is an inherently sociocultural process. The priorities and goals of stakeholders from students to faculty, advisors, and administrators must shift. The daily practice of many of these individuals will radically change. Mathematics faculty, as the primary participants in the community engaged around designing and implementing entry-level mathematics course options, must therefore be engaged in increasingly broad circles of participants. This faculty participation simultaneously grounds the changes in the expertise necessary for success and builds faculty's capacity to initiate and support change. Change as a process will require faculty leaders within the process to bring in other faculty to create sustainable change. As leaders within a culture and process of change (Fullan, 2001), faculty will need added support to take the change to scale and make it sustainable. Each of the key recommendations presented in this chapter focuses on mutually activating these aspects of faculty engagement.

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Lucy Hernandez Michal taught mathematics at El Paso Community College for many years. Along with her duties as a mathematics professor, she served as Research Projects Assistant to the Vice President of Instruction and Workforce Education and as Achieving the Dream Coordinator; she also led the College's Mathematics Pathways Team. Lucy currently serves as a Leadership Fellow for the Dana Center Mathematics Pathways (DCMP). Although retired, Lucy continues to advocate for equity in education and the central challenges faced during education reform.

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Chapter 2

Re-envisioning the Pathway to Calculus:

Supporting All Students

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Abstract

STEM occupations are expected to grow at a rate 1.4 times faster than non-STEM occupations, and the United States will need approximately one million more STEM professionals between 2014 and 2024. However, the declining number of students prepared to succeed in college-level calculus in their freshman year significantly reduces the pool of students likely to graduate with a STEM degree in four years. To broaden participation in STEM fields to meet the future demand for STEM professionals, institutions of higher education should reconsider how they prepare students for calculus in order to meet the needs of all students. By leveraging the opportunities presented by the mathematics pathways movement, institutions of higher education can make significant gains in student success and retention by attending to non-cognitive factors, identifying areas in calculus where students struggle, making mathematics meaningful for students through contextualization, focusing on developing a process view of function, and developing students' covariational reasoning skills.

Introduction: The Need for More STEM Professionals

Professionals in Science, Technology, Engineering, and Mathematics (STEM) fields help drive our nation's innovation and competitiveness. According to estimates from the Department of Commerce, STEM occupations are expected to grow at a rate 1.4 times faster than non-STEM occupations, and the United States will need approximately one million more STEM professionals between 2014 and 2024 (Noonan, 2017). At the same time, decreasing college readiness in mathematics coupled with poor success rates in developmental mathematics courses are negatively impacting the number of STEM degrees awarded. The declining number of students prepared to succeed in a college-level calculus course in their freshman year significantly reduces the pool of students likely to graduate with a STEM degree in four years (Kreysa, 2006). In response to poor success rates in developmental mathematics sequences, some state legislatures across the country are calling for reform by mandating that postsecondary institutions reduce the time that underprepared students spend in developmental mathematics courses. As a result, postsecondary institutions are left to grapple with addressing poor success rates for developmental mathematics students, while simultaneously needing to increase enrollments in calculus and the number of STEM graduates. These factors, combined with recent advances in mathematics education and the learning sciences, indicate the time has come to re-envision the pathway to calculus, which is essential to STEM majors. This chapter presents research on non-cognitive factors that are barriers for students, identifies mathematics education research about content and pedagogy to guide decisions about curriculum, and provides a framework for re-envisioning the pathway to calculus to broaden student participation in STEM fields.

Mathematics Pathways as a Catalyst to Re-envision the Pathway to Calculus

The mathematics pathways movement (see the Preface in this monograph) represents a significant shift in the approach that institutions of higher education are taking towards the content and sequencing of undergraduate mathematics education. In a growing number of states, mathematics departments are reallocating existing resources to increase student success in mathematics by decreasing enrollments in developmental mathematics, reducing the number of courses in traditional mathematics sequences, and providing mathematical content that is aligned to students' intended programs of study. A national study of mathematics departments found that 58 percent of two-year colleges implemented a mathematics pathway with redesigned courses in foundations, quantitative reasoning, and statistics in Fall 2015 (Blair et al., 2018, Table TYE.11, p. 176). Enrollment in introductory statistics at two-year and four-year institutions increased 45 percent between 2010 and 2015, signaling a significant change towards alignment (Blair et al., 2018, Table S.1). These shifts represent an opportunity to improve student outcomes. By providing meaningful mathematics pathways for students whose programs do not require calculus, institutions can focus their attention on designing appropriate mathematics pathways that will prepare STEM students for success in traditional calculus.

Supporting All Students: Attending to Non-Cognitive Factors

The task of supporting students on the pathway to calculus requires reflection about non-content issues that create barriers for underrepresented STEM students like women and underrepresented minority students. To broaden participation in STEM fields and fully realize the potential of mathematics pathways, mathematics faculty should work to minimize the negative impacts of three critical non-cognitive factors: lack of sense of belonging, lack of self-efficacy, and stereotype threat. Although these non-cognitive factors are relevant to student success across disciplines, strategies to reduce their negative impacts can be applied effectively in mathematics courses.

A sense of belonging reflects the feeling that one fits in, belongs to, or is a member of the mathematics community. A healthy sense of belonging is a significant predictor of one's intent to pursue mathematics in the future (Good et al., 2012). Strategies that enhance students' sense of belonging can be as simple as an instructor noticing that a student is absent and then contacting the student. Slightly more involved strategies include holding class discussions about effective work groups and developing classroom norms for working in collaborative groups. Self-efficacy, or one's belief in their ability to succeed, also plays a role in broadening participation in STEM programs, especially in the retention of women and underrepresented minorities. Women are 1.5 times more likely to leave STEM after completing calculus due to a lack of self-efficacy (Ellis et al., 2016).

To further enhance students' feelings of belonging and self-efficacy, institutions should leverage an important feature of the mathematics pathways movement: alignment of college algebra and precalculus courses to STEM programs that require calculus. Successfully aligning mathematics to programs of study leverages the use of contextualized mathematics that is meaningful to students. Contextualized mathematics provides opportunities for students to explore different approaches to problem solving at different levels of formality and makes mathematics more accessible and more likely to engage students in learning (Van den Heuvel-Panhuizen, 1999; Widjaja, 2013). From a cognitive perspective, contextualization promotes transfer of learning and retention of information (Boroch et al., 2007), which increases the probability of success in calculus and, consequently, student self-efficacy.

Stereotype threat contributes to the underperformance of women, African Americans, Latinos, and other minorities in mathematics (Aronson & Steele, 2005). At its core, stereotype threat is characterized by activated stereotypes that, when left unchecked, trigger a number of disruptive psychological processes that can undermine student performance (Croizet et al., 2004). The experience of being in a numeric minority in academic environments where stereotypes are part of the dominant culture reduces individuals' self-efficacy, especially in the face of difficulty, even if their actual performance is objectively the same as majority-group members (Dasgupta, 2011). A learning environment that utilizes group work, makes student learning visible, and showcases different student approaches to solving challenging mathematical problems can have a significant positive impact on student self-efficacy by making it evident that everyone must work hard to succeed. This in turn may diminish stereotype threat (Asera, 2001).

A recent study of the calculus redesign at Boise State University indicates that the core elements of frequent group work, making learning visible through active and collaborative learning, and contextualization produced sizable, sustainable, and statistically significant gains in Calculus I pass rates and grades (Bullock et al., 2016). In addition, the university's redesigned Calculus I course significantly improved STEM retention for women and underrepresented minorities. After implementation of the redesign, STEM retention rates of women and underrepresented minorities increased by more than nine percentage points (Bullock et al., 2017). This large effect significantly broadened participation in STEM programs at Boise State.

Pathway to Calculus: Content Considerations

While attending to non-cognitive factors can produce sizable gains in retention of women and underrepresented minorities in STEM programs, it is important to recognize that additional significant gains in student success can be made by vertically aligning the mathematical content used to prepare students for calculus. A process to facilitate discussion and action around curriculum redesign involves identifying areas in calculus where students struggle most, examining current research in mathematics education to anchor content and pedagogy decision in evidence-based research, and using the resulting information to create a relevant and engaging curriculum for students. As possible outcomes of this process are reviewed, specific content and other pedagogical choices will vary based on individual institutional and department needs. To begin the process, the authors of this chapter asked mathematics education researchers and calculus instructors, during a variety of professional development workshops, to give examples of areas of mathematics content where their students struggle in calculus courses (Boersma et al., 2015). The surveys produced the following list of potential problem content areas for calculus students:

- Algebra skills
- Functions and function notation
- Concepts of inverse functions and function composition
- Communicating about change and rates of change
- Limits and approximations
- The definite integral as an accumulator
- Dynamic geometric reasoning
- Overall problem-solving skills
- Working with open-ended problem structures

"Algebra skills" was identified as one of their students' major weaknesses even though many students enter college-level calculus classes having had years of algebra coursework in high school or college. Research in mathematics education indicates that some of students' algebraic difficulties are rooted in their superficial understanding of functions (Carlson et al., 2010; Oehrtman et al., 2008). This research has shown that when students develop a process view of a function, some problematic areas, such as inverting and composing functions as well as using function notation and symbols correctly, can be effectively addressed. Thus, what instructors identify as poor algebra skills may in fact be rooted in the lack of a deep understanding of functions.

To create a more meaningful approach to algebra, students should see, or discover for themselves, why each algebraic skill is useful. This can be accomplished by striving to contextualize many of the problems students encounter. Contextualization could entail engaging students with a self-contained meaning through modeling or showing explicitly how the skill will be used in later STEM courses. Context is key. It provides immediate meaning for students, a trigger to help them recall useful knowledge in later courses, and additional access points for students. Context also allows students to engage more quickly with the material (Perin, 2011; Schoenfeld, 2014). Additionally, instructors should strive to anchor algebraic skills with conceptual understanding of basic mathematics. For example, when addressing factoring, instructors could encourage students to realize the importance of factoring by seeing how a factored expression quickly yields different information than an unfactored expression, by exploring the connections between factors and roots, and so on.

To help build students' confidence and ability to persevere, instructors should help students discover their own strategies for performing certain algebraic manipulations and encourage students to share successful strategies with their peers (Abell et al., 2017; Schoenfeld, 2014). Most important, instructors can facilitate their classes in such a way that students realize that there is no single right way to "solve" a problem. The power of having students explore rich problems that allow for alternate approaches can also empower a broader range of students. Often if students simply use the skills they know, and use them correctly, they can eventually make progress and be successful in performing algebraic manipulations. Contextualizing content can provide immediate meaning for students and simultaneously increase their desire and/or willingness to struggle and persevere with a task.

Given students' repeated algebra experiences, faculty should keep three strategies in mind during students' pathway to calculus: (1) be aware of the mathematics education research about teaching and learning algebra; (2) take a meaningful approach to algebra in the classroom; and (3) provide more opportunities for students to build up confidence and perseverance in their algebraic abilities (Abell et al., 2017; Perin, 2011; Schoenfeld, 2014).

Additionally, research in mathematics education suggests that success in calculus is tied to students' ability to both gain a deep understanding of the function process and become proficient in covariational reasoning (Carlson et al., 2010; Oehrtman et al., 2008). Students usually exhibit either an "action view" or a "process view" of function. When students have an action view of a function, students tend to see functions as static entities and are typically focusing on computations involving evaluating functions at a single point (Carlson et al., 2010). Students who have developed an understanding of the process view of a function perceive functions as processes that can be composed and inverted; they understand that functions are processes that take a continuum of input values and produce a continuum of output values and that functions are used to model dynamic situations. Alternatively, students who lack the process view of a function:

- Have difficulty composing and inverting functions.
- Exhibit an inability to use functions effectively in word problems.
- View graphs of functions as fixed curves and not as a representation of a relationship between input and output values.
- View points on graphs and slopes of tangent or secant lines as fixed geometric properties of graphs and not as properties of the underlying function.
- Conflate the shape of a graph with the physical situation being modeled.
- Exhibit an inability to use symbols meaningfully.

In addition to developing a deep understanding of functions as processes, research shows that students should also develop the ability to apply covariational reasoning to a variety of situations (Carlson et al., 2010; Oehrtman et al., 2008). Covariational reasoning is the ability to consider how one quantity changes while imagining or visualizing changes in another quantity. Clearly this is an essential concept for understanding the major concepts in calculus. However, students who complete rigorous precalculus preparation may still have difficulty keeping two covarying quantities in their mind at the same time. These reasoning skills need to be intentionally introduced, developed, and mastered in any course or series of courses preparing students for calculus.

Rich Curricular Ideas, Pedagogical Strategies, and Student Success

Calculus instructors are challenged to decide how all of the mathematics education research presented above can best be realized in their classrooms. Based on research by Carlson et al. (2010), Oehrtman (2008), Perin (2011), and Schoenfeld (2014), the authors suggest the following eight instructional strategies:

- *Explore concepts with multiple representations:* Allow students to explore quantitative relationships represented with tables, formulas, words, and graphs as processes that can be represented in many different ways.
- *Emphasize that functions are processes and not algebraic formulas:* Whenever possible, focus students' attention on the underlying process that maps input values to output values. Allow students to try reversing the process (identify output values with input values) or composing it with other processes. Regardless of the representation being used, intentionally emphasize the difference between the process (function) and the representation.
- *Allow students to practice describing the behavior of functions on entire intervals:* Whenever students are evaluating functions at specific values, supplement this work with prompts that require students to consider an interval of input values or output values.
- *Develop the language and inclination to describe how one quantity changes with respect to another:* Contextualization provides an inclination to describe how quantities change. Use a curriculum that gives students daily practice in describing change such as average rate of change and the notions of increasing and decreasing.
- *Practice dynamic reasoning:* Provide students with many opportunities to describe dynamic situations such as heights of objects falling, distances and velocities of moving objects, geometric objects with changing dimensions, and so on.
- *Explore algebraic concepts within authentic STEM contexts and models:* Allow students to see the positive effects of algebraic manipulations within contexts that are related to their future fields of study. These modeling experiences reinforce the usefulness of algebra and encourage the exploration of multiple problem-solving strategies.
- *Build in frequent opportunities for students to practice communicating both orally and in writing:* Provide designated time in class for students to share results among themselves as well as with the entire class. Support and require written explanations, and give students formative feedback on how to improve.
- *Make the algebra meaningful!* Provide many contextualized problems as well as connect algebraic procedures with situations in which they are immediately meaningful to the students.

The above suggestions inextricably combine curricular ideas and pedagogical strategies. The success of a re-envisioned pathway to calculus is undoubtedly affected by both. Examining a student's preparation for calculus should not simply entail checking off a list of algebraic skills or function types they have been exposed to. Rather, faculty need to take into account specific methodology of how functions have been introduced and internalized, the amount of time students have had communicating about changing quantities and describing the relationships between changing quantities, and the opportunities available to students to explore algebraic concepts within an engaging context. These notions coupled with the non-cognitive factors identified earlier should be central to a student's pathway to calculus.

Conclusion

A well-designed pathway to calculus that focuses on the following can better serve a broad audience of students seeking STEM degrees:

- Minimize the negative impacts of critical non-cognitive factors.
- Make mathematics meaningful through contextualized mathematics.
- Understand the central role of algebra, functions, and change in the learning of calculus.
- Use research-based pedagogical strategies.

By attending to non-cognitive factors and providing appropriate content and support, the pathway to calculus can simultaneously remove barriers for vulnerable populations such as women and underrepresented minorities, provide the deep conceptual understandings of functions and covariational reasoning skills required for success in calculus, and allow all students to actively engage and persevere in contextualized and meaningful problem solving. The pathway to calculus should become a well-travelled highway that allows all interested students to enjoy the growing number of opportunities that come with the successful completion of a rigorous calculus course.

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Frank Savina leads the design, development, and implementation of the pathway to Calculus for the Dana Center Mathematics Pathways (DCMP). He presents findings at national and regional conferences of professional mathematics organizations to inform the mathematics community about best practices in preparing students for calculus. Additionally, Frank collaborates with faculty at two-year and four-year institutions to inform revision of the Charles A. Dana Center's higher education courses to better serve gateway mathematics students. Before joining the Dana Center, Frank spent 17 years teaching mathematics at the high school, community college, and university levels.

Chapter 3

Content Trends in Quantitative Reasoning Courses

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Abstract

This chapter traces the rise of quantitative reasoning (QR) course offerings, along with the factors that led to the wide variability in the content of those courses, the concerns that resulted from that variability, and the responses to those concerns. The advent of mathematics pathways has resulted in increasing numbers of students taking QR courses. This growth in QR enrollment has revealed issues with transfer between institutions and applicability to programs, resulting in increased costs to students in terms of both time and money. Research indicates that regions and states are moving toward standardization of learning outcomes to alleviate those issues. This chapter documents the trends in standardized mathematics outcomes in QR courses toward argumentation and communication, proportional reasoning, probability and statistics, and modeling as well as some common applications such as financial literacy and technology. Recommendations are presented for those looking to begin conversations about quantitative reasoning in their own region or state.

Introduction

The Quantitative Reasoning (QR) movement can trace its origins to the publication of the text, *Mathematics and Democracy* (National Council on Education and the Disciplines [NCED], 2001), which laid out the rationale for QR coursework in terms of requisite elements, expressions, and skills. The authors of this text point to an earlier document (Sons et al., 1996) for the list of skills that would help instructors plan curricula. Since that time, QR curricula have proliferated across the country with QR pathways introduced in 2009 and now available in many states and institutions. The goals and characteristics of these courses remain heavily influenced by the *Mathematics and Democracy* design team's admonition that "quantitative literacy is inseparable from its context. In this respect it is more like writing than like algebra, more like speaking than like history. Numeracy has no special content of its own, but inherits its content from its context" (NCED, 2001, p.17). This priority of developing the habits of mind required to be a numerate citizen over skill development has led to wide variability in the content and outcomes of QR courses. In an effort to help the mathematics community address the inconsistencies and issues of transferability of courses and applicability to programs, the authors of this chapter embarked on a research project to synthesize the extant learning outcomes in QR curricula at the state level.

In this chapter, the trends in both content and contexts among the states that have worked toward a standardized quantitative pathway are analyzed. In addition, recommendations for systems and states to develop consistent and coherent student learning outcomes that are relevant to students' programs of study and lives are presented.

Mathematics Pathways and Quantitative Reasoning Courses

The expansion of mathematics pathways is resulting in a proliferation of entry-level quantitative reasoning courses aimed at providing students with the mathematics needed to meet the quantitative demands of everyday life. The Mathematical Association of America (MAA) and other professional societies accelerated this process with a recommendation in 2015 for implementation of multiple mathematics pathways aligned to fields of study, some of which should include early exposure to statistics, modeling, and computation (Burdman, 2015; Saxe & Braddy, 2015). This recommendation grew out of the MAA's acknowledgment in 2004 that College Algebra was not an appropriate default gateway course for mathematics (MAA, 2004). In response, many institutions are redesigning College Algebra to serve solely as an entry point to the path to calculus for STEM and business majors, and aligning their remaining programs of study toward introductory statistics courses or a general education mathematics course to serve a quantitative pathway.

With today's highly mobile student population, transfer between institutions often leads to increased costs, lost credits, and decreased likelihood of completion (National Center for Public Policy and Higher Education, 2011). These issues have necessitated a closer inspection of the content of QR courses with the goal of standardizing learning outcomes and ensuring applicability. The last few years have seen movement toward standardization of the content among regional transfer partners and at the state level and across states.

A further complication has been that examples of the general education courses often required for liberal arts and fine arts and other similar programs are found under a variety of names such as quantitative reasoning, quantitative literacy, liberal arts math, contemporary math, and math in society, among others. Getz, Richardson, Hartzler, and Leahy (in press) noted the rise in enrollment of such courses in two-year colleges. According to the National Student Clearinghouse Research Center (Shapiro et al., 2017), 46 percent of all students who completed a degree at a four-year institution in 2013–2014 had been enrolled at a two-year institution at some point in the previous 10 years.

The content and intention of these QR courses have varied widely within and between systems and states. Examples abound of course descriptions that allow the instructor to choose the topics for the course from a list (e.g., Texas' former description stated, "Topics may include…."). The authors' analysis of 20 sets of "QR learning outcomes" from 18 states led to a differentiation between QR courses and Math for the Liberal Arts (MLA) courses grouped in the following categories (see table below).

The decision of which specific QR learning outcomes to include under MLA courses was partly due to four or fewer states choosing these for their QR courses and partly due to the authors' inspection of MLA textbooks' tables of contents. The five broad categories for QR courses listed in Table 1 will be broken down into specific learning outcomes and analyzed in more depth in a following section.

States and Their Courses

The content of these QR courses is starting to crystallize in several leading states (Gaze, 2014), but much variability remains across the country. Research during the summer and fall of 2017 uncovered 18 states that have common learning outcomes for courses that we will describe as being under the QR umbrella (see Table 4; note that there are 20 sets of outcomes due to two courses each in Georgia and Florida). Many of these outcomes are mandated from the state level but, in a few locations, they are simply an informal agreement across institutions. The outcomes vary from broad to highly prescriptive. Florida provides an example of a broad outcome, asking instructors to introduce students to "the beauty and utility of mathematics." On the other end of the spectrum, Georgia specifies in part

Table 1. Broad learning outcomes for QR courses vs. specific outcomes for MLA courses

QR Courses (broad categories)	MLA Courses (specific outcomes)
Argumentation/Communication	Math Appreciation
Proportional Reasoning	History of Math
Probability and Statistics	Sets
Modeling	Geometry
Applications	Graph Theory
	Art
	Across Disciplines

that students should "be able to distinguish among linear, quadratic and exponential growth models." Common QR student learning outcomes also range from very sparse (27 words in Arkansas) to highly detailed (six-plus pages in Ohio and Virginia).

Content and Context

Inspection of the 20 sets of QR learning outcomes reveals many commonalities in content. For example, 14 sets of outcomes stipulate instruction in statistics while 13 indicate probability content. However, the depth and breadth of the outcomes related to these two topics differ among the states, such as ranging from descriptive statistics to statistical inference. The term *modeling* is used in only five outcomes documents, but various modeling topics permeate almost all of the examples.

See Table on the next page.

Table 2. Number of states selecting learning outcomes using the authors' designation of QR vs. non-QR

QR Courses	# of States
Argumentation/Communication	
Critical thinking	5
Decision-making/prediction	5
Communication	10
Analyze arguments	6
Construct arguments	7
Logic	7
Proportional Reasoning	
Estimation/precision/ reasonableness	7
Convert within/between different measurement scales	5
Rates/percentages/decimals	3
Number sense	7
Uses and abuses of percentages	3
Proportional reasoning	5
Absolute and relative change	4
Probability and Risk	
Probability, odds, risk	13
Statistics	14
Modeling	
Linear, non-linear, exponential growth	8
Modeling	5
Algebraic, symbolic reasoning	7
Multiple representations	10
Applications	
Use appropriate technology	8
Develop problem solving strategies	8
Real-world data applications	8
Consumer/financial math	12
Citizenship, social issues, voting, fair division	4

Non-QR Courses	# of States
Math for the Liberal Arts	
Math appreciation	3
History of math	3
Sets	4
Geometry	2
Graph theory	2
Art	1
Across disciplines	2
Miscellaneous	
Numbers and number systems	1
Elementary number theory	2
Systematic counting	1
Logarithmic functions	2
Optimization	1

Similar content may be described in a variety of ways. For example, probability content in Table 2 is sometimes stated as instruction related to odds or risk. Some outcomes refer to absolute and relative change; others require work with linear and exponential functions; and still others stipulate simple and compound interest. These related concepts may range from numerical work to symbolic work or both. Most outcomes contain little guidance as to the expected depth. More than half of the documents indicate the need to move between representations, thus spanning the range between numerical and symbolic forms.

The outcomes in Table 2 also illustrate that mathematical learning outcomes and application are often conflated. At least 12 outcomes reference financial math, with varying degrees of specificity. Ohio provides a robust example of separation of mathematics outcomes from their application as well as specificity of depth. Outcome 2.4 calls for the use of "basic logarithm properties" and then suggests sample tasks such as finding "the time required to achieve a personal savings goal."

Many state outcomes documents also contain ideas that may be more accurately described as pedagogical recommendations, cross-disciplinary goals, or expectations for use of tools. At least half specifically mention communication as a learning outcome or as a goal of the course, while others imply it (e.g.,"interpret solutions," "show an understanding…both orally and in writing"). A majority refer to critical thinking and/or problem solving, concepts that can be interpreted in many ways and difficult to measure. Seven are explicit about the use of technology to perform certain tasks or analyses.

These differences in structure could lead to a variety of organizational strategies. Table 2 shows how many states selected each specific outcome. For example, five states list "critical thinking" and five states list "decision making," but it is unclear if these are the same five states or 10 distinct states. To get a picture of how often states identified each broad category, the authors have broken out how many states have selected only one learning outcome from a category, only two learning outcomes, etc. Table 3 shows that 18 states have selected at least one learning outcome associated with the broad category of Argumentation/ Communication. Of these 18 states, seven have selected only one learning outcome from this category, and six have selected two, while only one state selected all six learning outcomes for the category.

Table 3. Broad categories for QR courses broken down by number of states selecting a given number of specific learning outcomes from each category

QR Courses (broad categories)	Number of States Selecting Various Number of Specific Outcomes							
	Any	1	2	3	4	5	6	7
Argumentation/Communication	18	7	6	2	2	0	1	NA
Proportional Reasoning	12	3	2	3	1	3	0	0
Probability and Statistics	14	13	14	NA	NA	NA	NA	NA
Modeling	14	5	6	2	1	NA	NA	NA
Applications	17	4	7	1	4	1	NA	NA

The outcomes from Arkansas, Michigan, and New Mexico do not align with the structure of the remaining states' outcomes. As noted earlier, the Arkansas outcomes are very brief and broad, calling for students to develop a basic understanding of and appreciation for mathematics; develop the ability to think and reason critically, quantitatively, and logically; and be able to analyze arguments. Michigan adapted its outcomes from the Association of American Colleges and Universities Quantitative Literacy Rubric, listing and describing the skills of interpretation, representation, calculation, application/analysis, and communication (Michigan Right Math & the Right Time Working Group, 2018). New Mexico requires students to construct and analyze graphs and/or data sets, use and solve various kinds of equations, understand and write mathematical explanations using appropriate definitions and symbols, and demonstrate problem-solving skills within the context of mathematical applications. It is worth noting that many traditional algebra courses could claim to satisfy these generic outcomes.

Call for Further Action

The effort to standardize the quantitative pathway outcomes and content is encouraging. In order to bring consistency across institutions and states, the following action items are recommended:

- Additional states or regions should undertake the work by forming a working group with broad representation from the field, collecting the recommendations of professional associations, and referring to work done in other states.
- States should follow the lead of North Carolina (see Todd & Wagaman, 2015), Indiana, Ohio, and others by including and codifying a focus on real data and source material as well as authentic applications that are relevant to all students' lives (i.e., financial, civic, risk literacy). Real data and sources are more engaging for students, demonstrate the life relevance of the mathematics, and can help prevent artificial problem constructs. *Mathematics and Democracy* calls for engaging our students with complex problems that are "anchored in data derived from and attached to the empirical world" (NCED, p. 5) and emphasizes that in a QR course, "content is inseparable from pedagogy and context is inseparable from content" (NCED, p. 18). Perhaps most important, analysis of authentic sources naturally leads to an understanding not only of uses of mathematics, but also of misuses, and can result in students who think for themselves rather than consume media reports. Steen (1999) asserted that "numbers have become the chief instruments through which we attempt to exercise control over nature, over risk, and over life itself" (p.10).
- A clear delineation in outcomes documents between mathematics content and the applications that must or may be used to demonstrate the relevance of those mathematics outcomes should be created.
- Within the classroom, the mathematics content should not be isolated from context; students must be able to apply their mathematical skills. Madison (2001) noted that applying mathematics is not easily learned, so instruction must contain the contextual use of the skills.
- Specificity in the mathematics outcomes and applications, which leads to clearer expectations of depth and breadth and therefore promotes transparency between transfer partners, should be encouraged.
- Lastly, much of the work in setting common outcomes impacts community colleges more than four-year institutions. Transfer among four-year institutions and reverse transfer from four-year to two-year institutions is also high (Shapiro et al., 2015). Consideration should be given to setting a common standard in two-year and four-year institutions in order to facilitate the attainment of relevant mathematics content and promote program completion.

In closing, the critical need for helping students gain the necessary skills to navigate the quantitative world we inhabit cannot be overstated. Robust quantitative reasoning curricula can empower students to fully participate in today's data-driven society. It is imperative that work continue on developing the fundamental skills outlined in this chapter that are required for informed decision making for all citizens.

Table 4. Courses in the Quantitative Reasoning umbrella

State	Course Number	Course Name
Arkansas	Math 1003	College Math
Florida	Math 106	Math for Liberal Arts I
Florida	Math 107	Math for Liberal Arts II
Georgia	Math 1001	Quantitative Reasoning
Georgia	Math 1101	Introduction to Math Modeling
Indiana Ivy Tech	Math 123	Quantitative Reasoning
Kansas	Mat 1040	Contemporary Math/Essential Math
Louisiana	CMAT 1103	Contemporary Mathematics
Maryland		Topics for Mathematical Literacy
Michigan		Quantitative Reasoning
Missouri		Mathematical Reasoning and Modeling
Montana	M105	Contemporary Mathematics
Nevada	Math 120	Fundamentals of College Math
New Mexico	Math 1110	Quantitative Reasoning
North Carolina	Mat 143	Quantitative Literacy
Ohio	TMM011	Quantitative Reasoning
Oregon	Math 105	Math in Society
Texas	Math 1332	Contemporary Mathematics (QR)
Virginia CCS	MTH 154	Quantitative Reasoning
Washington	Math &107	Finite Math in Society

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Chapter 4

The Evolving Statistics Pathway

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Abstract

Statistics is the gateway mathematics course for a large and growing number of students. Institutions across the country are exploring ways to broaden access to college-level introductory statistics courses through new placement and prerequisite policies. As access to introductory statistics is opened to accommodate a group of students that is more diverse with respect to mathematics preparation, support structures are being put in place to enable mastery of student learning outcomes that are consistent with course guidelines for the introductory statistics curricula that have been endorsed by the American Statistical Association (ASA). These support structures include courses for mathematically underprepared students, such as co-requisite courses and pre-statistics courses that are clearly focused on the mathematics that is needed for success in introductory statistics. This chapter considers issues related to placement, course content recommendations, and support course models designed to provide a meaningful educational experience for students pursuing a course of study that has statistics as the gateway mathematics course.

Introduction

The need to rethink how students experience college-level mathematics is clear and compelling. In California alone, every year more than 100,000 community college students who are judged to be unprepared for college-level mathematics and placed into a traditional developmental mathematics sequence never go on to complete a college-level gateway mathematics course (Huntsman, Hern, & Snell, 2016). This is far from the intended outcome of developmental education, which was to help students be successful in postsecondary coursework. Hern and Brezina (2016) aptly noted that "the policies and curricula that higher education has developed to help students who are considered 'underprepared' are actually making them less likely to succeed in college." In response, and with the support of mathematics and statistics professional societies, many institutions are exploring and implementing other approaches. Providing multiple entry-level mathematics pathways that are better able to accommodate diverse student interests and career goals is proving to be an effective approach.

Because introductory statistics was noted as the appropriate gateway mathematics course for a large and growing number of students (Mathematical Association of America, 2004), many institutions and organizations have worked to develop a "statistics pathway." There is now growing evidence that implementing a carefully planned statistics pathway—in addition to the traditional algebra-intensive pathway needed for STEM majors—can result in striking increases in the number of students completing the college-level statistics course. This success has been documented at a number of two-year and four-year institutions. For example, the Tennessee Board of Regents (2016) reported that after full implementation of statistics pathways at both two-year colleges and four-year universities, there was a substantial increase in the number of students passing the credit-bearing statistics course in their first year. This increase was seen at both the two-year and the four-year institutions, and across all levels of student preparation in mathematics. The California Acceleration Project (CAP) has worked to promote and support accelerated statistics pathways (pathways that enable students traditionally placed into the developmental mathematics sequence to complete transfer-level statistics in one or two semesters). CAP reported that accelerated pathways improved student completion of the introductory statistics course for students at all placement levels and for students of all ethnic backgrounds (Hayward &Willett, 2014). Other notable success stories are described in Huang and Yamada (2017) and Henson, Hern, and Snell (2017).

Considering these documented early successes, both individual institutions and statewide systems (such as in Tennessee and Texas) are implementing statistics pathways (as well as quantitative reasoning and STEM/calculus pathways) on a grand scale. The Conference Board of the Mathematical Sciences (CBMS) 2015 Statistical Abstract of Undergraduate Programs in the Mathematical Sciences in the United States (Blair, Kirkman, & Maxwell, 2018, Table TYE.11) reported that 58 percent of responding community colleges have implemented a pathways course sequence, and 63 percent of those who have one or more pathway sequences have implemented a statistics pathway. Others are just at the beginning of this process and may benefit from careful thought around several key issues, including placement, the content and pedagogy of the college-level introductory statistics course, and the design of support structures for students who may be underprepared in mathematics upon entry to the introductory statistic course. These issues will be addressed in the sections that follow.

Placement

The shift to implement a statistics pathway requires rethinking how entering students are placed into their first college-level mathematics course. In the traditional system, the thinking was that if students could be appropriately positioned at the correct entry point in the traditional sequence of three developmental mathematics courses, it would improve the rate at which they moved on to and completed the college-level mathematics course appropriate to their chosen program of study. However, research on the "accuracy" of various placement instruments found that most were only weakly correlated to pass rates in either developmental or college-level gateway courses (for examples, see Belfield & Crosta, 2012; Jenkins, Jaggers, & Roksa, 2009). The resulting call for improved placement tests did little to improve the situation. The long sequence of developmental mathematics courses and the implicit message to students placed into these courses that they are not ready for college were at the heart of the problem—not necessarily just the placement tests.

In the multiple pathways model, placement takes on a new meaning, and there are two types of placement that need to be considered. The first is placement into the appropriate pathway—for example, statistics, quantitative reasoning, or STEM/calculus. This placement is critical and requires good advising to ensure that students enter a pathway that is appropriate for their anticipated area of study. A full discussion of this type of placement can be found in *A Call to Action to Improve Math Placement Policies and Processes* (Couturier & Cullinane, 2015).

The second type of placement that institutions must grapple with is which students are permitted entry into the college-level introductory statistics course. Some implementations still require students to complete a developmental pre-statistics, or "pre-stat," course prior to entering the introductory statistics course. The difference between this and the traditional developmental pathway is that this pre-statistics course is focused on the mathematics that students need to be successful in statistics (which is a subset of the content in the traditional three course developmental sequence), and it is only one semester (compared to as many as three in the traditional developmental sequence), allowing students to complete the college-level course in the first year of study. In the pre-stat model, a determination will need to be made about who is required to take pre-statistics and who goes directly to the college-level statistics course. This approach is similar to the more traditional placement decisions, but valid placement instruments that assess for just the statistics-relevant mathematics content do not currently exist.

In contrast to the pre-stat model, what appears to now be emerging as the dominant statistics pathway model is the co-requisite, or "co-req," model, which allows all students to move directly into the introductory statistics course and provides additional support for those students who need it. Many people were skeptical of this approach, but institutions that have experimented with the co-req model have surprisingly positive results, as illustrated in the discussion below.

Based on data from a randomized controlled experiment, Logue, Watanabe-Rose and Douglas (2016) concluded that there is evidence that many students directed into developmental mathematics can pass the college-level statistics course without full remediation. In the study, 717 students who placed into developmental mathematics were randomly assigned to one of three groups. Those in the first group were enrolled directly into a college-level statistics course with a two-hour workshop support. Those in the second group were required to enroll in the traditional developmental algebra course prior to taking statistics, and those in the third group were enrolled in the developmental algebra course with a two-hour workshop support prior to taking statistics. Researchers found that at the end of the semester, 56 percent of the students assigned to the college-level statistics group passed the course, whereas the pass rates in the developmental algebra course for students assigned to the two developmental algebra groups (with and without workshop support) were 39 percent and 44 percent, respectively. In follow-up, they also found that the students who were placed directly into and passed statistics were no less likely to have passed other general education courses (including science).

In California, in the last few years some community colleges have also dramatically altered placement policies for entering students, including using multiple criteria in addition to or as a replacement for traditional placement tests. College of the Canyons now offers direct placement into statistics for any student who meets any one of five criteria, including a high school GPA of 3.0 or higher or a grade of B- or higher in high school algebra (Saxena, Meuschke, & Gribbons, 2017). These changes in placement resulted in 71 percent of entering students being considered eligible to enroll in college-level statistics. Of 408 students who would previously have been required to take developmental algebra but who enrolled directly in statistics, 66 percent were successful in their first attempt (Henson, Hern, & Snell, 2017). At Cuyamaca College, prior to revising its placement policy, only 24 percent of entering students were considered eligible to enroll in statistics. After implementing changes to placement procedures, 84 percent of entering students were considered eligible for statistics with co-requisite support. Pass rates in the statistics course were unaffected by broadening access, with an overall pass rate of 74 percent (Henson, Hern & Snell, 2017). At Long Beach City College, with the implementation of a new placement policy, the percentage of students placed directly into college-level mathematics courses increased by 23 percentage points. Follow-up studies showed no significant differences in mathematics course success rates after the placement change was implemented (Long Beach City College Institutional Research, 2014).

Content and Pedagogy of the Introductory Statistics Course

Of course, increasing student success and progress to degree is not as simple as just opening access to the college-level statistics course by changing placement policies. Placement is only one component in what needs to be a comprehensive approach to designing a successful statistics pathway. The institutions that have been successful have also taken care to ensure that the content and pedagogy of the statistics course are appropriate and that additional support is provided for students who need it. When considering broadening access to statistics, a good starting place is a close look at the existing statistics course. It makes sense to review existing content prior to determining what sort of support structure would be most beneficial.

Research in mathematics education supports the belief that student learning is enhanced when students experience mathematics in an active way, engaging in activities that develop conceptual understanding and working collaboratively to solve meaningful problems. Findings from many of these research studies are summarized in a report on active learning published by the Conference Board of Mathematical Sciences (CBMS), an organization whose membership comprises the 17 mathematics professional societies in the U.S. This CBMS report (2016) included the following statement: “We call on institutions of higher education, mathematics departments and the mathematics faculty, public policy-makers, and funding agencies to invest time and resources to ensure that effective active learning is incorporated into post-secondary mathematics classrooms." This statement clearly applies to the introductory statistics course, and this is an important part of the design of the statistics course intended as the gateway course in a statistics pathway. Exemplary statistics pathway models, such as Dana Center Mathematics Pathways, Carnegie Math Pathways (Statway™), and the courses in the programs mentioned earlier in this chapter, all provide rigorous and intellectually challenging statistics curricula that embrace active learning. As diversity in the student population in the statistics course increases, the more important attention to pedagogy becomes.

Further guidance on content, pedagogy, and focus of the introductory statistics course can be found in *Guidelines for Assessment and Instruction in Statistics Education College Report* (GAISE College Report ASA Revision Committee, 2016), published by the American Statistical Association (ASA). In addition to articulating goals for the college-level introductory statistics course, the report also contains recommendations that include teaching statistical thinking, teaching statistics as an investigative process of problem solving and decision making, giving students experience with multivariable thinking, focusing on conceptual understanding, fostering active learning, and integrating real data with a context and a purpose.

Statistics courses that are planned as the entry-level mathematics course in a statistics pathway should be aligned with these CBMS and ASA recommendations. Once faculty have aligned (or verified that an existing course is already in alignment) with the recommendations of the professional community, learning outcomes for the course can be articulated. It is important that these be student learning outcomes and not just a list of content topics because this will make the next step (developing appropriate support) easier.

Models of Support for Underprepared Students

There are currently more examples of fully implemented successful statistics pathways (such as the ones referenced in the previous sections) than is the case for other pathways because it was the first pathway to be fully developed. It is also currently the appropriate pathway for a large number of students. There is no single "right" way to provide support for underprepared students embarking on the statistics pathway, and several different approaches have proven to be successful.

One approach requires that underprepared students take a one-semester developmental course prior to enrolling in the statistics course. While this pre-stat model still requires the student to take a developmental course, the pre-stat course is focused on the mathematics and other cognitive and affective skills that are thought to be directly related to success in statistics. Completed in a single semester, the course accelerates student progress toward completion of the college-level statistics course in the first year. In planning this type of support course, it is helpful to begin with the learning outcomes for the statistics course. For each learning outcome, faculty can reflect on what prerequisite skills will be required for a student to be able to achieve that outcome. The set of skills identified in this manner then leads to the learning outcomes of the support course and, in turn, the content of the support course. For an example of mathematics prerequisites identified in a process similar to the one described here, see Peck, Gould, and Utts (2015).

The co-requisite support or co-req model is currently the most common model, a consequence of work supporting the effectiveness of the approach (e.g., Vandal, 2014) and legislative pressure to reduce or eliminate remedial courses in many states. In this model, students enroll directly in the college-level statistics course. Then those students determined to be underprepared are also enrolled in a co-requisite support course that is taken concurrently with the statistics course or may even be integrated into the statistics course itself. There are many interesting and functional variations on this theme. For a deeper discussion of co-requisite support courses, see Richardson and Dorsey (this volume). While the co-req model is a support model that is different from the pre-stat model, the process described earlier for developing course learning outcomes and content is also appropriate for the design of a co-requisite course.

Conclusion

There is compelling evidence that underprepared students for whom statistics is the appropriate gateway college-level mathematics course are far better served by being placed in an accelerated statistics pathway that allows completion of statistics in a single semester or by the end of the first year of study. There are now a few models (e.g., co-requisite, pre-statistics) that have been shown to be successful in increasing student success in statistics and in facilitating progress to degree. Although these models differ in various ways, the successful models discussed here have common elements.

- They have all ensured that the introductory statistics course is a rigorous and intellectually challenging course for students and that the course is aligned with current recommendations from the relevant professional societies.
- They have addressed issues of pedagogy and have incorporated active learning in a way that contributes to student learning.
- At the same time, they have modified placement policies to allow broader access to college-level statistics without compromising the level or content of the statistics course.
- To accommodate broader access, they all have taken steps to provide appropriate support for all students entering this accelerated statistics pathway, with a particular attention to support for those students who may be underprepared in mathematics.

Because of documented successes like the ones described here, many institutions are looking to implement a statistics pathway. Institutions that have made this change have noted a marked increase in enrollment in the introductory statistics course, which in turn can create challenges that should be anticipated. The increased enrollment in statistics has staffing implications, and the demand for faculty, especially adjunct faculty, who are qualified to teach statistics has increased and will continued to increase. Even faculty who have previously taught statistics may find themselves uncomfortable with the changes in the course and the ways in which it is taught that come with alignment with the CBMS and ASA recommendations. The need for professional development and support for faculty who are teaching statistics for the first time or who may be transitioning into a mode of teaching that is not entirely lecture-based is greatly needed.

While the challenges are not ones that have a quick or easy solution, institutions should not be deterred from addressing them head-on and moving to implement a statistics pathway. If student success and progress toward degree completion are a priority, it is imperative to consider an accelerated statistics pathway, alternative placement policies, and support structures for underprepared students. The evidence is compelling and calls for action.

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Chapter 5

Key Considerations in Designing Co-requisite Supports

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Abstract

Postsecondary developmental mathematics sequences were designed to give underprepared students more time to master mathematical concepts and to improve success in the college-level course. However, research indicates that these sequences often become a barrier even for students who pass individual courses. Many institutions and their students are finding success with co-requisite courses, placing underprepared students directly into college-level courses with additional supports. Many systems and states implementing such strategies have been experiencing success, with some seeing five to six times the number of students passing their first college-level mathematics course in half the time or less. This chapter explores the structural, cultural, and content decisions made by institutions in implementing co-requisite courses, such as those related to student placement, curricular design, and whether just-in-time supports are separate or embedded. The chapter presents the results of interviews with faculty and administrators at two-year and four-year institutions. Key considerations for designing co-requisite courses are delineated and supported with institutional examples. Recommendations drawn from the learning sciences are also provided.

Introduction

The term *mathematics pathways* refers to a mathematics course or sequence of courses that college-ready or underprepared students take in order to meet the requirements of their program of study. The two critical principles in developing mathematics pathways are that students should engage immediately with mathematics content that supports their program of study and that systemic structures should enable them to complete a transferable course within their first year of college (Charles A. Dana Center, n.d.). Pathways courses and sequences have been most often available in Quantitative Reasoning, Statistics, and Algebra/STEM (Science, Technology, Engineering, Mathematics).

Traditional developmental content and course structure in mathematics often works at odds with these two principles. Long developmental mathematics sequences can mean two years or more of remediation, even for students who successfully complete each course in the sequence. Long sequences also offer multiple exit points for students who fail a class or fail to register for the next class in a sequence (Bailey, Jeong, & Cho, 2010; Xu & Dadgar, 2016). Also, much of the content in the traditional sequence is designed to be relevant primarily for students who are in a STEM degree program, while content that would support success in a wider range of fields is lacking.

Co-requisite course instruction is becoming a popular strategy to accelerate mathematics course completion and to ensure that students are entering directly into an appropriate mathematics pathway at the college level. While there are many versions of co-requisite instruction, the broad definition refers to the placement of students who have been designated as underprepared directly into college-level courses and providing additional supports.

The implementation of co-requisite strategies has been shown to act as a multiplier in the percentages of students passing their first college-level mathematics course in states and systems across the country. Some institutions and states that have implemented co-requisite structures are reporting five to six times the number of students completing a college-level course within one semester or one year. For example, the Tennessee Board of Regents Office of Institutional Research reported that, even in the first year of implementing corequisites, 60 percent of students completed their developmental requirements and college-level course in one semester when previously, 12 percent completed the same courses within a year (Denley & Knox, 2016). Other institutions and systems have reported similar success rates with co-requisite courses, with 70 percent of students or more completing their developmental requirement and college-level course in one semester. (For more information on the history of co-requisite models, see Adams, Gearhart, Miller, & Roberts, 2009; Asera, 2001.)

In response to these successful initiatives, the Charles A. Dana Center has received queries from the field about the best model for co-requisite mathematics. In order to learn more about the specifics of co-requisite implementation at two- and four-year institutions and systems that self-reported success to the field, Jennifer Dorsey, a member of the Dana Center evaluation team, conducted in-depth interviews with mathematics faculty and administrators to determine to what these institutions and systems attribute their success (see Appendix A for the interview protocol; see Appendix B for participants in the Dana Center's data gathering). Selected artifacts from these interviews and our other interactions with the field can be found by searching for "co-requisite" at dcmathpathways.org.

This chapter presents the learnings from these interviews. What is clear from those conversations is that there is no single way to successfully implement co-requisite courses on a campus, but there are specific areas where decisions will need to be made when designing a course sequence. Content considerations and strategies for building a strong learning culture within the corequisite classroom, along with a look at the broader context of comprehensive redesign that often leads to even stronger results, are included in this chapter. In addition, recommendations are provided for co-requisite implementation and continuous improvement based on the Dana Center's extensive experience in the field.

When designing and constructing the co-requisite model(s) that will best serve each institution (and each pathway), many decisions should be made in collaboration with faculty, advisors, administrators, and financial aid staff. These decisions revolve around three large categories of considerations: structures, content, and culture.

Considerations When Designing Co-requisite Course Programs

At institutions with widespread co-requisite success, strong pathways implementation has been of fundamental importance. At those institutions, only calculus-intending students are in an algebraically-intensive sequence; students in programs that do not require calculus are placed in a course more appropriate to their goals, such as introductory statistics or quantitative reasoning. In Tennessee, for example, over 60 percent of students take statistics as their gateway mathematics course (Jenkins, Brown, Fink, Lahr, & Yanagiura, 2018). Indiana's statewide community college system, Ivy Tech, enrolls approximately half of its students in a quantitative reasoning course. In other states, it varies by institution whether students are predominantly in statistics, quantitative reasoning, or the algebraic pathway.

Designing the Structure of Co-requisite Courses

Co-requisite courses take many forms: boot camps, extended hours each week with embedded support content, separate but linked support courses that run throughout the semesters, mandatory tutoring, compressed courses, stretch courses, and other structures—all of which enable a student to complete a college-level course while receiving developmental mathematics support (see Appendix C). Structural considerations also include factors such as staffing, placement, and whether to have students co-mingle or be part of a cohort.

Co-requisite Designs

Many co-requisite designs can be used together successfully; in fact, a combination of designs may be called for. Many institutions have found that separate but linked support courses work well for quantitative reasoning or statistics courses, but they have struggled with that structure for the algebraic/STEM pathway. Instructors note the difficulty of starting College Algebra at the beginning of the semester when students have algebraic deficiencies. To compensate, the College Algebra course is often offered as a cohort model. This structure allows the developmental content to be frontloaded with many of the fundamental algebraic skills that will be needed as soon as the college-level content begins. A frontloading alternative to cohort classes for College Algebra is the boot-camp model in which a short course runs at the beginning of the semester and then a co-mingled structure begins after four or five weeks. Such frontloading is generally not necessary for other pathways.

Regardless of the design structure or the pathway, repeated information from the field found that more highly structured courses result in better success. Teresa Adams from the Community College of Denver reports that her institution's original model basically functioned as a homework hour, resulting in disengagement by students and frustration on the part of faculty. When faculty changed the model to include more targeted interventions to prepare students for the upcoming class, the climate of both the college-level and the support classes changed. The developmental students became more engaged and confident, often becoming the leaders of the college-level class.

If a co-requisite course is designed for students who are only slightly underprepared (e.g., placed at the Intermediate Algebra level under the old system), then one additional hour of support per week may be sufficient. If the co-requisite course is designed to replace multiple levels of developmental content, then several additional hours per week may be necessary. Dr. Christopher Herald at the University of Nevada–Reno reports that the general education mathematics course is supported by one additional co-requisite hour, while the Precalculus 1 course has two additional hours of support. Dr. Markus Pomper at Roane State Community College notes that his institution's three-credit-hour statistics course is paired with three hours of support. The Dana Center advises to "over-plan" supports initially, and then reduce the hours if the data indicate it may be feasible to do so.

Staffing

Co-requisite design teams sometimes do significant planning and design work before realizing they created a structure that they cannot staff. Developmental courses may be staffed with faculty who lack the credentials to teach college-level courses and/or are not trained to teach statistics or quantitative reasoning when pathways are designed. However, there is not a clear distinction between staffing a cohort and staffing a co-mingled class. It is possible to have one instructor with a co-mingled class and possible to have two instructors with a cohort class.

Cohort or Co-mingle

Some institutions have gravitated toward a cohort model so that the remediation takes place "in the moment." For example, San Jacinto College uses a cohort model for College Algebra that meets seven hours per week. The class moves seamlessly between college-level work and remediation as needed. This model requires a common instructor (some institutions use two co-instructors) and may be difficult or impossible to implement if college-level credentialed instructors are in short supply. Alternatively, choosing a co-mingled model

Table 1. Cohort and co-mingle with one and two instructors

	Cohort	Co-mingle
One instructor	Can be run as two distinct classes or as one seamless class with all of the same students	Must be two distinct classes (college-level and separate support class)
Two instructors	Two distinct classes with all of the same students	Must be two distinct classes (college-level and separate support class)

allows the institution to choose to continue utilizing developmental staff to teach the support course. There may still be staffing difficulties as the increase in college-level sections may strain the capacity of the department but the challenges would not seem as extreme if those sections were taught under a single-instructor cohort model. Additionally, in the co-mingled model, developmental students are able to attend college courses with their college-ready peers, which gives them access to classmates with more diverse ability levels.

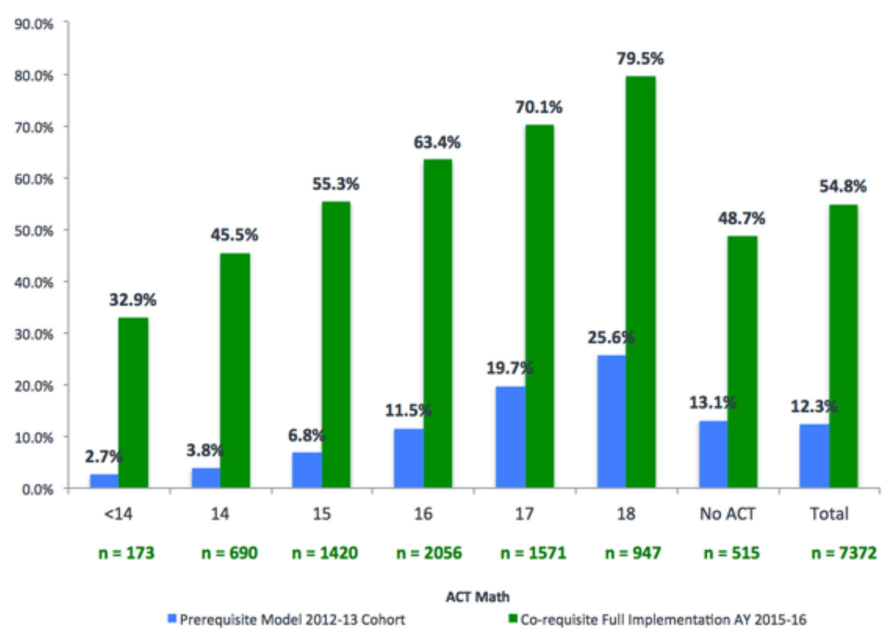
Placement

Placement into co-requisite courses is achieved in a variety of ways at college campuses, with some institutions placing only "bubble" students, or students who are missing the cutoff score for college placement by only a few points, into co-requisite courses. Other colleges and systems, including the Tennessee system (Denley & Knox, 2016) are placing all developmental students directly into college-level courses with co-requisite support with positive results.

Multiple measures placement has resulted in more students being placed directly into credit-bearing math courses, rather than remediation. Some institutions allow students with uneven academic records (e.g., sufficient high school GPA but low placement score or vice versa) to opt into supports, while students who are low in both GPA and placement score are required to take the support course. Cuyamaca College, a member of the California Acceleration Project, reports that multiple measures placement drastically reduced the number of students needing support courses, while simultaneously making great gains at closing achievement gaps.

Placement can also vary by pathway; if the existing placement instrument is algebraically-intensive, it may be given less consideration for placement into non-algebraically-intensive pathways courses. For those students still deemed as underprepared for college-level work, co-requisites are being employed as just-in-time remediation and extra time on task to directly support the appropriate pathways course.

Figure 1. Tennessee community colleges gateway math success in one year (adapted from Denley, 2016)



Designing the Content of Co-requisite Courses

Historically, all underprepared students received the same developmental mathematics instruction that focused on algebraic skills. Institutions that have redirected students to mathematics courses that are better aligned with programs of study are able to rethink and customize the skills content instruction provided. Rather than looking backward at a standardized marker of middle school and high school mathematics content, designers are able to look forward: What knowledge, skills, and strategies will meet the underprepared students where they are, and move them forward to success in their aligned gateway course? What other cultural considerations are needed?

For calculus-intending students, their needs are still heavily algebraic, and the only question is how much of the prerequisite content they are missing and when and how it will be provided. Offering a typical Intermediate Algebra course alongside a typical College Algebra course is unlikely to improve outcomes and may create further confusion, as the support content will usually be out of sync with the college course. Design teams will have greater success if they start from a departmentally standardized college algebra course and backmap to determine the essential foundational concepts to provide to students in the support course. Sometimes these programs also use the support course to build in additional time on the college-level content.

Students in liberal arts, health sciences, and social sciences are often served by a quantitative reasoning or introductory statistics course. Underprepared students in those pathways should receive support content that is appropriate for those courses. For example, underprepared students in introductory statistics are best supported with extra instruction in decoding statistics problems, determining which statistical test is appropriate, and analyzing results. Underprepared students in quantitative reasoning courses are provided extra instruction in numeracy, proportional reasoning, modeling, and statistical literacy. Dr. Becky Moening, from Ivy Tech Community College in Indiana, stresses the importance of the designers of the gateway course and the support course working closely together to ensure that the supporting content aligns and that the design teams engage in regular continuous improvement cycles. Roane State Community College created a co-requisite instructor manual with a common course calendar and student worksheets for its statistics co-requisite course.

Mathematics requirements for Business and Education programs vary broadly. There are examples in which these programs are aligned to College Algebra, quantitative reasoning, and statistics as well as to specialized business math and education math courses. Regardless of the required college-level course, the most successful institutions align the support content to the gateway content.

Other Content Considerations

Some institutions report student disengagement in support courses. In order to build urgency for students, most programs provide separate assessments to students in the support course. The determination of final grades varies, but one common structure is shown on the next page.

In addition to consideration of time on support content and college-level content, many programs devote some amount of time in the support course to learner success strategies. These strategies include explicit instruction in goal-setting, self-regulation, and the value of struggle, all of which can increase persistence.

Table 2. Pass/fail support courses at Roane State Community College in Tennessee

	Pass college-level course	Fail college-level course
Pass support course	Gen Ed is requirement satisfied. Unless other math courses are needed, remediation requirements are satisfied.	Student repeats college course. Repetition of remedial class is optional.
Fail support course	Gen Ed is requirement satisfied. Unless other math courses are needed, remediation requirements are waived.	Student repeats both classes.

The Comprehensive Approach and Recommendations

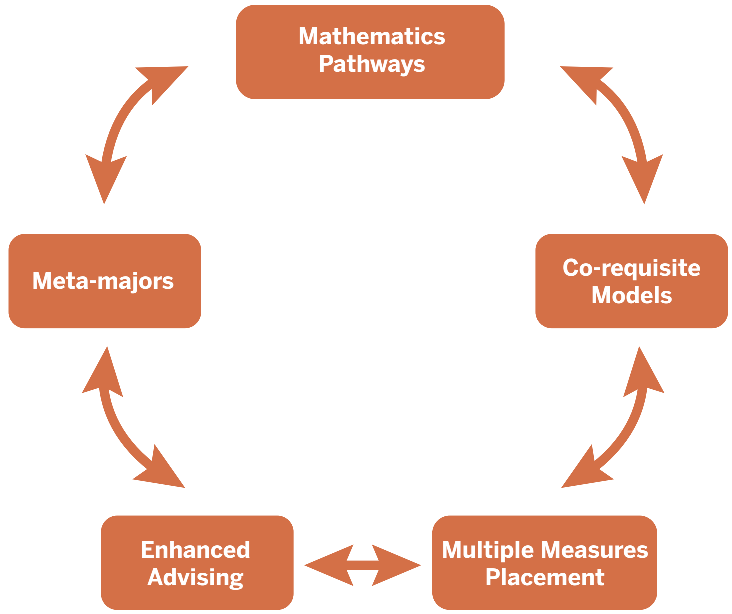
Culture Considerations

Although not exclusive to co-requisites, culture shifts are taking place across the country due to changes in funding models and, in some areas, declining enrollments.

- Shifting the culture of the department from "sink-or-swim" to "we're all in this together" is a component of many successful programs. Departments that have focused on early referral have seen increased success and decreased withdrawals.
- Emphasizing this collaborative culture with students has often resulted in the organic formation of peer support groups.
- Explicit instruction about the purpose and benefits of the co-requisite model can help to mitigate student concerns about taking additional or extended mathematics in one semester.
- Ongoing formative assessment, rather than solely relying on a few major exams, has resulted in earlier interventions and increased success. Implementing such shifts can pay off in an increased sense of belonging to both the class and the campus, as well as increased feelings of capability and purpose.

The canvassing of successful pathways programs revealed that co-requisites were not implemented in isolation. Just as co-requisite supports are implemented in diverse ways, institutions are implementing pathways, meta-majors, and multiple measures placement in a variety of ways in order to best serve their student population and local context. Several of the major interventions are illustrated in the following graphic and are described more fully in other chapters of this monograph.

Figure 2. Co-requisite models are most effective when embedded within comprehensive redesign efforts



The use of meta-majors with common, relevant, default math courses has been credited with reducing the problem of large numbers of students with undeclared programs, thereby allowing students to be placed into an appropriate mathematics course in their first semester.

Early in the evolution of co-requisite courses, most programs started with pilot courses and sometimes only involved students near the cut score of placement exams. However, attempting to scale up a pilot co-requisite course can sometimes reveal what Uri Treisman calls "inconvenient truths" that may have been ignored in the pilot development. Sufficient evidence of the success of co-requisites (when compared to traditional developmental sequences) exists; therefore, we recommend a comprehensive approach including:

- Planning with a vision for scale. Planning teams should aim for full implementation, face and honor the inconvenient truths, implement, and then engage in continuous improvement.
- Implementing multiple measure placement. Provide additional avenues by which students can demonstrate readiness for college-level coursework. Placement tests that are heavily algebraic should be used with caution for non-STEM-intending students.
- Choosing pathways based on the student's stated academic and life goals. Planning and implementation teams should guard against the danger of placing students into those pathways based on a low placement score.
- Cohorting and co-mingling both have passionate advocates.

  Some institutions report that the cohort model has increased students' sense of belonging by giving them an instant community.

  Other institutions report that co-mingling increases the sense of belonging to the institution. While we see the value *in each, we are concerned that a cohort class could be viewed as "lesser."*

The Dana Center recommends co-mingling as a model that more clearly maintains the integrity of the college course while welcoming students into the college community.

Combining the integrity and inclusiveness of the college course with the staffing benefits of co-mingling tips the scales for us into the co-mingling camp.

- Similarly, there is a lack of agreement about the need for structured content versus using the support course as a tutorial or homework time. There are successful programs in both camps. However, we believe that students benefit when departments agree on the content and calendar of both courses so that all faculty have faith in the integrity of the courses.

- Understanding your data. Inspecting pass rates of individual courses is insufficient. Ask the institutional research department to provide longitudinal data on developmental students. What is the current true percentage of students who complete a gateway mathematics course within two years, if they initially placed two levels down? What portion of the non-completers were actually successful in their courses but stopped out somewhere along the way?

- Engaging in continuous improvement.

  Compare gateway course completion data to the baseline data described above.

  Survey stakeholders, including students, to gather information on how the structures are working and where modifications may be needed.

  Analyze course assessments to see where continued content refinement may be needed.

Given the information and recommendations presented in this chapter, think about your own college and policy context and decide what may work best for your students. Key considerations are how you will structure the course, how you will staff the courses, how you will organize the content for the two courses, and how you will place students into courses. Plan **now** for continuous improvement!

Appendix A
Co-requisite Instruction Interview Protocol

Background Information

1. School/campus name:
2. Two-year or four-year institution?
3. System/state: (Is your college a part of any system?)
4. Contact person/information:
5. How big is this program at the college (as proportion of similar students)?
6. What structures are in place such as guided pathways, pedagogy alignment?

Course Implementation Methods

7. Student grouping: Cohort or Co-mingle?
8. Course structure: Boot camp, Compressed courses (e.g., 8x8, 4x12), Mandatory tutoring, Stretch courses (across two semesters), Support courses that run alongside college-level?
9. Class size
10. Grades: One grade or separate, does one affect the other?

Course Placement Criteria

11. Student choice, advisor recommendation, faculty recommendation, test score?
12. Advising mandatory? For which students?
13. Which test do they use: Single test, combination of various tests?
14. Score range for eligibility
15. Bubble students only? Yes/No

Credit Hours/Financing

16. Students:
    a. Total credit hours awarded, how many are college-level, how many count towards degree?
    b. How many hours do they pay for?
17. Faculty:
    a. Total credit hours that count towards load, how many hours are they paid for?
    b. How many hours are they paid for?

Staffing

18. Type: College level faculty, adjunct, lab attendant?
19. Same or different staff for co-requisite and main course?
20. Number of staff present during class hours (one, two?)

Co-Requisite Course Content

21. Syllabus: Same across the campus or not?
22. Types of courses offered (stats, college alg., QR or contemporary math, etc.)
23. Non-cognitive content embedded? (study skills, self-efficacy, brain malleability, etc.)
24. Does co-requisite content align to college-level course content? How?

Evaluation of the Program

25. Completion of the program of study/graduation rates
26. Student completion of college-level course (include time frame)
27. Would you be willing to share any of this data with us? Aggregate data?

Program History

28. When did you start the program?
29. Did you start with a pilot or at scale? (or somewhere in between?)
30. Have you made significant changes since then?

Additional Information

31. Is there anyone else we should talk to?
32. If we decide to do some case studies or other publications in this area, would you be interested in participating further?

Appendix B

Participants in Dana Center Data Gathering

Individuals from the following institutions and organizations took part in data gathering, including surveys and interviews, conducted by representatives of the Charles A. Dana Center:

Arapahoe Community College, Colorado Community College System, Colorado
Central Texas College, Texas
Chancellor of Community Colleges, West Virginia
College of Coastal Georgia, Georgia
College System of Tennessee
Community College of Denver, Colorado
Elkhart North Central Region, Ivy Tech Community College System, Indiana
Georgia State Perimeter College, Georgia
Georgia State University, Georgia
Kilgore College, Texas
Roane State Community College, Tennessee
South Texas College, Texas
Tennessee Board of Regents, Tennessee
Texas State Technical College, Texas
Warsaw College, Ivy Tech Community College System, Indiana

Appendix C
Definition of Terms

- **Cohort:** Courses that separate college-ready students and underprepared students who are taking co-requisite courses into separate college-level courses. A cohort of underprepared students may take one class with extended hours,in which the support is embedded as needed, or there may be two distinct, linked courses, one in which college content is addressed with the other providing the support.
- **Co-mingle:** Courses that mix college-ready and underprepared students who are taking co-requisite support courses into the same college-level class. Underprepared students are provided additional support, which may take the form of advance work, such as a boot camp. Most commonly, the support is ongoing throughout the semester, as an additional class that meets on a regular schedule or required tutoring or lab time.
- **Structures:** How courses are offered "on the books."
    - **Boot camp:** First 3–5 weeks of the semester are remediation, followed by the college-level content (classes meet extra hours each week throughout the semester in order to equal the two classes or class plus lab).
    - **Compressed courses:** Developmental prerequisite class is compressed into 8 weeks, and then the college-level class is compressed into 8 weeks, so that both classes are completed in one semester (classes meet extra hours each week throughout the semester in order to equal the two classes). Note that this model contains a transition point, providing a risk that students will stop out.
    - **Mandatory tutoring:** Required attendance in a tutoring lab for a specified number of hours per week.
    - **Stretch courses:** College-level classes with the developmental content embedded and stretched over two semesters (e.g., Statway™ model). This model also risks student stop-out at the semester break.
    - **Support courses:** Structured support courses that run before, after, or on opposite days to the college-level courses; completed within one semester.

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About the authors

Connie Richardson leads the curriculum development team for the mathematics courses for the Dana Center Mathematics Pathways (DCMP). She also supports the development of DCMP's professional learning offerings related to curricular redesign, co-requisite supports, and pedagogy. In this work, Connie collaborates with faculty to identify best practices and disseminate to the field. Connie has 14 years of experience at the high school level, teaching a wide variety of courses, including Advanced Placement Calculus and Statistics. She also has more than nine years of experience at the university level, teaching developmental and college-level mathematics and teacher preparation courses.

Jennifer Dorsey serves as a research and evaluation analyst at the Charles A. Dana Center, specializing in qualitative research, and leads the evaluation of the Dana Center Mathematics Pathways (DCMP). She works with Center staff to design and conduct research and evaluation of the DCMP and analyze, interpret, and report results. Jennifer also works with external evaluators of the DCMP, including MDRC, the Community College Research Center, and Shore Research Group. Additionally, she serves as a qualitative research consultant for other projects at the Dana Center, including work with the Academic Youth Development program and the Urban District Leadership Network.

Section 2

System, State, and Administrator Engagement

Chapter 6

Higher Education as a Complex Adaptive System:

Considerations for Leadership and Scale

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Abstract

As state policies, economic pressures, and enrollment declines increase pressure on higher education systems to rapidly improve student outcomes in mathematics, many institutions have transformed the way they do business and have adopted mathematics pathways at scale. At the same time, many systems of higher education have struggled to move from piloting mathematics pathways to implementing reforms at a scale that supports every student's success in postsecondary mathematics. Drawing on complexity science, this chapter presents a conceptual framework for leaders at all levels of higher education systems to design change strategies to adopt mathematics pathways principles at scale. How leaders think about the systems that they work in has material consequences for designing, implementing, and sustaining scaling strategies. The chapter offers a framework and recommendations for understanding higher education as a complex adaptive system and the role of strategic leadership in designing, implementing, and sustaining reforms at scale.

Introduction

After decades of innovation and research on improving student success in postsecondary mathematics, a convincing body of evidence has emerged about high-leverage strategies that ensures students have equitable access to and success in mathematics. As a result, many states and higher education systems have begun adopting mathematics pathways principles for all students by transforming policies, practices, and cultural norms anchored in system-level student success strategies. Today, leaders of higher education systems are leveraging what has been learned from the collective efforts of system-level mathematics pathways reforms. By sharing promising practices, research, and strategies, faculty, staff, and administrative leaders are contributing to transformational changes in policies and practices at a scale that support all students.

Despite the successes, many states and systems struggle to integrate mathematics pathways with the myriad student success initiatives that exist across many academic and administrative departments. A substantial body of literature has amassed around policy implementation and the problem of scaling. Programs that begin as pilot projects with the intent of "scaling up" rarely take root as a transformational change across a system. At the same time, policies mandated from system governance or legislatures are often underfunded and unenforceable, limiting the sustainability needed for broad and deep implementation.

This chapter draws on the field of complexity science as a lens for examining the relationship between systems transformation and scale. Using the mathematics pathways movement in higher education systems as a case study, the chapter offers a framework for understanding transformational change in higher education and the role of strategic leadership in designing, implementing, and sustaining reforms at scale.

Higher Education as a Complex Adaptive System

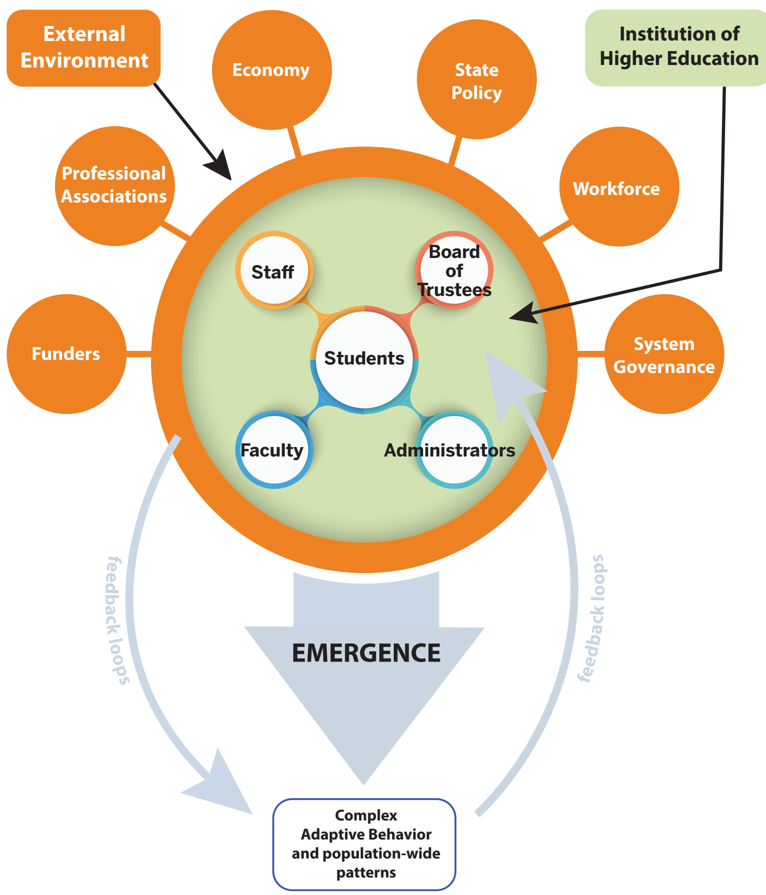
The term *system* refers to a set of connected parts that together form a complex whole. Systems are integral to the way we live our lives and undertake our work. While many such systems can be described as complicated, others are complex and adaptive. Automobiles, for example, characterize a system of highly specialized mechanical parts that work together to transport people between points. The automobile represents a highly complicated system, one that must function consistently based on a limited set of hierarchical rules such as accelerating, braking, and turning. In contrast, the traffic flows created by the sum of all automobiles moving between different points represents a *complex* and *adaptive* system. Traffic is complex because it sits at the intersection of many other complex systems, such as government policy, population shifts, and geography, to name a few. Traffic is also adaptive because its flow constantly changes as a dynamic function of the micro-level interactions of *both* automobiles with one another *and* automobiles nested within the larger systems that constitute transportation policy and infrastructure.

An emerging body of literature has begun to apply concepts and methodologies from the science of complex adaptive systems theory to understand the dynamics of change in human systems. Scholars and systems leaders have contributed to this research by using complex adaptive systems theory to better understand the dynamics of transformational change in higher education systems. Complexity science can offer a powerful conceptual framework for how leaders at all levels of higher education systems think about their roles in designing, participating in, and sustaining scaling strategies for mathematics pathways.

Complexity science has its origins in the natural sciences and mathematics. Meteorologists first formalized models of complex systems by creating computer simulations to model the interaction and coevolution of weather systems (Burnes, 2005). Research into complex adaptive systems seeks to understand how macro-level features of systems emerge from the self-organizing, micro-level interactions of individual agents within the system.

In the case of the meteorologists, the task is to understand how hurricanes emerge from the complex interaction of many dynamic weather systems to design better models and improve early warning alerts for affected areas. For leaders of education systems, the question becomes how to create a holistic understanding of the systems they seek to change and designing strategies that can harness the systems' collective energy to achieve broad, deep, and sustained scale.

Figure 1. Complex adaptive behavior and population-wide patterns



Higher education systems, like living organisms, must constantly adapt and evolve to ensure survival in response to ever-changing system dynamics. While a treatment of the technical features of complexity science is beyond the scope of this chapter, Figure 1 offers a simple visual model for understanding how institutions of higher education fit within a complex adaptive systems view. In this model, institutions of higher education can be understood as organizational systems made of diverse, active, interdependent agents (students, staff, faculty, and administrators) interacting and adapting on the basis of "knowledge, experience, feedback from the environment, local values, and formal system rules" (Keshavarz, Nutbeam, Rowling, & Khavarpour, 2010, p. 1468). At the same time, institutions of higher education are nested in a larger ecosystem of complex systems that dynamically exchange information and exert environmental pressures on one another. It is through the iterative feedback loops between the internal and external systems that the policies, practices, and cultural norms embodied by the institution emerge.

Leadership for Scale in Complex Adaptive Systems

While the application of complex adaptive systems theory in education settings is relatively new, research from this field has suggests design principles that higher education leaders can use to develop, implement, and evaluate scalable reforms (Frank, Muller, Schiller, & Riegle-Crumb, 2008; Maroulis, Guimerà, Petry, Stringer, Gomez, Amaral, & Wilensky, 2010); White & Levin, 2016). Since complex adaptive systems research focuses on systems that can evolve over time, research into these systems can trace the attributes, behaviors, and relationships that influence changes in individuals and which result in collective changes at the system level (Mandviwalla & Schuff, 2014). The mental models that leaders within higher education institutions use to understand systems and scale matter because they shape the tactics and strategies for achieving student success goals.

First, varied understandings of the term *scale* shape how leaders design reform strategies. "Unidimensional" definitions of scale, such as defining the success of a particular reform as the degree to which it spread across sites, are insufficient for capturing what is in essence a multidimensional change process. Instead, a complex systems view requires a complex understanding of scale. Coburn (2003) offers a reconceptualization of scale that accounts for the complex adaptive features of education systems:

> *Taking an external reform initiative to scale is a complex endeavor. It not only involves spreading reform to multiple teachers, schools, and districts . . . it also involves all of the challenges of implementing reform documented by decades of implementation research and of sustaining change in a multilevel system characterized by multiple shifting priorities. It is the simultaneity of these challenges, in all their complexity, that makes the problem of scale fundamentally multidimensional. (p. 3)*

Coburn argues that scale should be described along four axes: spread, depth, sustainability, and shift in reform ownership. *Spread* refers to the adoption of reform principles across different institutions. *Depth* refers to the quality and nature of reform to have consequential change in all classroom practice by altering the "beliefs, norms of social interaction, and pedagogical principles" of faculty, staff, and administrators (Coburn, 2003, p. 4). Since institutions are situated in and inextricably linked to a turbulent external environment, *sustainability* indicates the durability of a reform to persist over time in the face of a changing environment. Finally, *shift in reform ownership* highlights the need to design scaling strategies that create conditions for the authority and knowledge of a reform to transition from an external group to faculty, staff, and administrative leaders at all levels of an institution.

Just as higher education institutions and scaled reforms have complex adaptive systems features, leadership itself can be understood as a complex dynamic process (Hazy & Uhl-Bien, 2015; Lichtenstein & Plowman, 2009; Lichtenstein, Uhl-Bien, Marion, Seers, & Orton, 2006). Leadership is defined as an emergent event that occurs in the interactive spaces between people and ideas. In applying complexity science to leadership theory, researchers seek to understand the role of leadership in expediting and sustaining change processes, and creating conditions through which the interdependent actions of many individuals combine to create a system that is greater than the sum of its parts (Lichtenstein et al., 2006).

The most sustainable and adaptable systems are characterized by strong ties between the agents in a network. finding value and meaning in the information sharing that leads towards collective goals. Drath (2001) writes, "People construct reality through their interactions within worldviews . . . [they do it] when they explain things to one another, tell each other stories, create models and theories . . . and in general when they interact through thought, word, and action" (p. 136). Accordingly, leadership is not just the action of a single individual; rather, leaders emerge from the interactions between agents over time.

Boal and Schultz (2007) have characterized strategic leadership in complex adaptive systems in the following way:

> *In complex adaptive systems, strategic leaders affect organizational learning and adaptation . . . by telling stories and promoting dialogue in which an organization's past, present, and future coalesce: stories and dialogue about our history; stories and dialogue about who we are; stories and dialogue about who we can become. . . . Through the evolving process of storytelling, strategic leaders achieve innovation and change by demonstrating its legitimacy and consistency with the past. Maintaining this balance—between the past and future, between stability and disorder—allows organizations to evolve and learn. (pp. 426–427)*

Institutions of higher education are constructed from the interaction of students, staff, faculty, and administrators working towards the shared goal of student learning and success. Accordingly, strategic leaders can affect organizational learning and change by creating the conditions for all agents in the system to work together towards shared goal.

Mathematics Pathways in Complex Adaptive Systems

The Charles A. Dana Center coined an operational motto for scaling strategies built on the recognition of overlapping systems of power within and between institutions of higher education: "Faculty-driven, administrator-supported, policy-enabled, culturally-reinforced, and student-centered" (2018). This description of working at scale offers a touchstone for articulating specific actions across all levels of a higher education system and provides groundwork for key considerations of leadership in complex adaptive systems.

In the Dana Center's implementation work across many states and a variety of systems, one primary challenge to scaling continues to be aligning mathematics pathways between institutions of higher education. The success of students who transfer between institutions of higher education offers one powerful example for understanding the intersection between mathematics pathways reforms and complex systems theories.

More than 40 percent of all undergraduates enroll in two-year institutions and at least 80 percent of these students intend to transfer and earn a bachelor's degree (Jenkins & Fink, 2015). Based on the most recently available federal data, at least 35 percent of all undergraduate students transferred at least once from 2004 to 2009 (Government Accountability Office, 2017). Despite the high student mobility rates between institutions, very few transfer-intending students ever complete a degree. Jenkins and Fink (2016) estimate that only one-third of transfer-intending students ever matriculate to a four-year university, and less than 15 percent earn a bachelor's degree.

These data suggest that one feature of many students' experience of higher education is navigating a web of diverse policies, practices, and curricula at a variety of institutions. While many, and sometimes all, mathematics courses will transfer between institutions, many courses may only count as elective credit and may not consistently or transparently apply towards a specific degree program. In many states and systems, programs of study that are similar have varied mathematics requirements. In higher education systems, the lack of coordination and coherence of mathematics course requirements across institutions presents challenges for students, advisors, and faculty when helping students enroll in courses that meet their needs as transfer students.

A small set of studies use complex adaptive systems theory as a framework for understanding the relationship between transfer institutions and the behaviors of agents within those systems that can promote or hinder transfer student success. Kisker (2007) uses systems theory to study the processes that promote community college and university transfer partnerships. Specifically, Kisker's research is based on the concept of "network embeddedness," meaning that "an institution's external and internal 'social networks' are the most influential factors shaping organizational behavior" (p. 285). Through a series of interviews with stakeholders at one university and nine community colleges, Kisker found that ongoing faculty involvement is critical for effective transfer partnerships. In addition, strong relationships between transfer partners are built on a history of trust and sustained by a culture that promotes communication and coordination.

Leaders can strategically frame ideas such as mathematics pathways in a way that honors an institution's mission and history and engages individuals at all levels of the system in processes that work towards cooperation instead of competition. Three principles derived from research on leadership in complex adaptive systems can be used to support the scaled adoption of mathematics pathways:

- Leaders must create conditions for stakeholders at all levels of an institution to self-organize and work together in mutually beneficial ways. The most robust and sustainable systems are made up of decentralized, yet tightly connected networks of agents. When these stakeholders at all levels of an institution are supported in their work, empowered to make decisions, and actively encouraged to work as a team, they use their collective wisdom to predict challenges and quickly adapt.
- Leaders should create meaningful feedback loops that allow for rapid iteration of ideas and strategies. Change represents the only constant feature of a complex adaptive system, and leaders understand this phenomenon well as it relates to institutions of higher education. Evolution is a process of "trial and error," not "trial and success." In order to design reforms that can sustain themselves through the ever-shifting currents of policy, economy, and social norms, leaders must actively encourage refinement and be willing to learn from mistakes.
- Third, a healthy institutional culture is a precondition for the success of any reform, especially reforms aimed at fundamentally changing policy and practice at scale. In complex adaptive systems, context matters. The trajectory of how change unfolds is highly sensitive to initial conditions. Effective leaders must have a grounded understanding of the conditions of their systems and a clear vision for the organizing principles

that will move the system to transformation. For example, how leaders think and speak about scale has material consequences for the success of a scaling strategy because the definition of what counts as "scale" shapes what counts as "success." An institutional culture based on trust and open communication between stakeholders and grounded in an explicit commitment to equitable student success will create the conditions for sustainable change. Leaders are the arbiters of institutional culture and must consistently model the values, norms, and beliefs that they hope to see reflected in everyday practice.

While mathematics courses represent a small piece of most students' postsecondary experiences, a rigorous, relevant, and aligned pathways experience can be crucial for their success. Leaders working to promote mathematics pathways principles within their institutions can draw on lessons from complex adaptive systems research to influence the strategies and approaches for scaling and sustaining reforms.

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Chapter 7

Dana Center Mathematics Pathways (DCMP) Theory of Scale:

Exploring State-Level Implementation Successes and Challenges

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Abstract

In 2014, the Charles A. Dana Center at The University of Texas at Austin developed a theoretical model called the Dana Center Mathematics Pathways (DCMP) theory of scale, which defined a four-phase approach to coordinating, implementing, and scaling multiple mathematics pathways across diverse higher education ecosystems. This chapter highlights how the Dana Center has supported the four phases of system- and institutional-level engagement through its work across the country. An exploration of strategies within each phase is examined alongside successes and challenges encountered in six states that were engaged in the Dana Center Mathematics Pathways to Completion (MPC) project.

Introduction

National data reveal that 60 percent of incoming students at two-year postsecondary institutions are placed into at least one developmental mathematics course each year. Many students must complete several developmental courses before becoming eligible to take college-level mathematics courses. Only 33 percent of these students complete the developmental mathematics sequence, and only 20 percent complete a college-level mathematics course (Bailey, Jeong, & Cho, 2009).

In response to these trends, in 2012, the Charles A. Dana Center launched the implementation of the Dana Center Mathematics Pathways (DCMP) model in nine Texas two-year postsecondary institutions in conjunction with the Texas Association of Community Colleges. The work called for the reform of developmental and gateway mathematics programs in higher education institutions following a systemic approach to improving student success (see Charles A. Dana Center, n.d.). The DCMP model is based on the four principles of multiple mathematics pathways aligned to programs of study, acceleration, integrated student learning strategies, and evidenced-based instruction and pedagogy (Cullinane, Fraga Leahy, Getz, Landel, & Treisman, 2014). This chapter examines the DCMP theory of scale, its four-phase approach to system- and institutional-level engagement, and how the Dana Center has supported its work to scale the DCMP model across the country. To highlight the DCMP theory of scale and its four-phase approach, successes and challenges of state and institutional expansion of the DCMP model are identified for stakeholders who are interested in implementation.

The DCMP Theory of Scale: Implementation Across Higher Education Ecosystems

Propelled by the Dana Center's experiences with its DCMP model in Texas, the Center published the Dana Center Mathematics Pathways (DCMP) theory of scale in 2014, which offers a multi-faceted approach to coordinating, implementing, and scaling multiple mathematics pathways across diverse higher education ecosystems. The basis of the DCMP theory of scale is to support the Dana Center's evolving approach to scale the DCMP model and the process for its enactment.

The DCMP theory of scale draws upon Rogers' (1995) diffusion of innovation theory, Coburn's (2003) conceptualization of breadth and depth of scale, DiMaggio and Powell's neo-institutional theory (1983), and Kingdon's three streams theory (1984) to postulate the essential behaviors, attitudes, and actions that are necessary to influence sustainable "change at scale" (Cullinane et al., 2014). The DCMP theory of scale presumes that established processes and strategies across multiple educational ecosystems and phases of work could result in normative, sustained practice for all students enrolled in mathematics pathways. The pinnacle of the DCMP's theory is the concept of **change at scale**, defined as implementation of mathematics pathways *across* all public institutions (breadth) and *deeply* within institutions (depth) so that all students are engaged in high-quality, rigorous, and well-supported learning experiences. Figure 1 illustrates change at scale across multiple educational ecosystems.

Supporting All Students: Attending to Non-cognitive Factors

The task of supporting students on the pathway to calculus requires reflection about non-content issues that create barriers for underrepresented STEM students like women and underrepresented minority students. To broaden participation in STEM fields and fully realize the potential of mathematics pathways, mathematics faculty should work to minimize the negative impacts of three critical non-cognitive factors: lack of sense of belonging, lack of self-efficacy, and stereotype threat. Although these non-cognitive factors are relevant to student success across disciplines, strategies to reduce their negative impacts can be applied effectively in mathematics courses.

A sense of belonging reflects the feeling that one fits in, belongs to, or is a member of the mathematics community. A healthy sense of belonging is a significant predictor of one's intent to pursue mathematics in the future (Good et al., 2012). Strategies that enhance students' sense of belonging can be as simple as an instructor noticing that a student is absent and then contacting the student. Slightly more involved strategies include holding class discussions about effective work groups and developing classroom norms for working in collaborative groups. Self-efficacy, or one's belief in their ability to succeed, also plays a role in broadening participation in STEM programs, especially in the retention of women and underrepresented minorities. Women are 1.5 times more likely to leave STEM after completing calculus due to a lack of self-efficacy (Ellis et al., 2016).

To further enhance students' feelings of belonging and self-efficacy, institutions should leverage an important feature of the mathematics pathways movement: alignment of college algebra and precalculus courses to STEM programs that require calculus. Successfully aligning mathematics to programs of study leverages the use of contextualized mathematics that is meaningful to students. Contextualized mathematics provides opportunities for students to explore different approaches to problem solving at different levels of formality, and makes mathematics more accessible and more likely to engage students in learning (Van den Heuvel-Panhuizen, 1999; Widjaja, 2013). From a cognitive perspective, contextualization promotes transfer of learning and retention of information (Boroch et al., 2007), which increases the probability of success in calculus and, consequently, student self-efficacy.

Stereotype threat contributes to the underperformance of women, African Americans, Latinos, and other minorities in mathematics (Aronson & Steele, 2005). At its core, stereotype threat is characterized by activated stereotypes that, when left unchecked, trigger a number of disruptive psychological processes that can undermine student performance (Croizet et al., 2004). The experience of being in a numeric minority in academic environments where stereotypes are part of the dominant culture reduces individuals' self-efficacy, especially in the face of difficulty, even if their actual performance is objectively the same as majority-group members (Dasgupta, 2011). A learning environment that utilizes group work, makes student learning visible, and showcases different student approaches to solving challenging mathematical problems can have a significant positive impact on student self-efficacy by making it evident that everyone must work hard to succeed. This in turn may diminish stereotype threat (Asera, 2001).

A recent study of the calculus redesign at Boise State University indicates that the core elements of frequent group work, making learning visible through active and collaborative learning, and

Figure 1. Change at scale requires work at multiple levels of the system

contextualization produced sizable, sustainable, and statistically significant gains in Calculus I pass rates and grades (Bullock et al., 2016). The Dana Center's position is that change at scale must involve effort at all levels of the higher education ecosystem. At the national level, the Dana Center joins national leadership organizations and mathematics professional associations to advocate for multiple mathematics pathways as a means to increase equity and access for all students (see a list of collaborators at www.dcmathpathways.org/dcmp/our-collaborators). The Dana Center's work at the state level (or system level) coordinates and promotes scaling of mathematics pathways through a mathematics task force to develop recommendations for multiple mathematics pathways, and to enact such recommendations and policy-enabling conditions to support statewide implementation. Finally, at the institutional and classroom levels, the Dana Center provides a process, resources, and tools to institutional stakeholders in order to implement and scale mathematics pathways as sustained, normative practices. Early experimentation at the local, institutional, and classroom levels has raised new ideas that inform and influence higher levels of the system.

The DCMP theory of scale describes a system- and institution-level engagement framework for how sustained change at scale can be enacted. This framework (see Figure 2) involves four phases of work necessary for full-scale implementation of mathematics pathways into sustained, normative practice (Cullinane et al., 2014).

Figure 2. DCMP theory of scale's phases of work for system- and institutional-level engagement

Table 1 further defines the four phases of system- and institutional-level engagement and the established strategies within each phase to move toward sustained scale.

Table 1. DCMP theory of scale's phases and strategies for system- and institutional-level engagement

Phase	Strategies
Phase 1. Build urgency and motivation for change through a state mathematics task force.	• Create a collective agenda. • Define the problem with state- or system-level data.
Phase 2. Create an environment and supports for statewide implementation.	• Coordinate action across all levels of the educational ecosystem. • Establish multiple working groups to enact task force recommendations.
Phase 3. Enact multiple mathematics pathways at the institution(s).	• Seek and define early engagement with institutions. • Provide tiered engagement and the corresponding supports.
Phase 4. Support deep and sustained scale.	• Intentional structures for sustainability of change.

The Dana Center's Mathematics Pathways to Completion (MPC) Project

In 2015, the Dana Center launched the Mathematics Pathways to Completion (MPC) project as a major effort to support six states—Arkansas, Massachusetts, Michigan, Missouri, Oklahoma, and Washington—to move from the broad theoretical vision for mathematics pathways to institutional implementation of the Dana Center Mathematics Pathways model over three years. In the MPC project, each of the six states engaged in processes, strategies, and phases defined by the DCMP theory of scale. The Dana Center provided direct support in the form of consultations, resources, and tools. As a result of the MPC project, the Dana Center learned valuable lessons about operationalizing the DCMP theory. The MPC states' strategies, successes, and challenges in implementing the DCMP theory of scale are presented below, followed by findings and recommendations for future work.

Strategies, Successes, and Challenges of Phase 1 of the MPC Project

When implementing the DCMP theory of scale and building motivation for change in Phase 1, the Dana Center recommended that MPC states create state-level task forces comprised of mathematics faculty from both two-year and four-year institutions. The Dana Center charged the state-level task forces to create a collective agenda about implementing mathematics pathways that involved defining the problem being addressed, using state- or system-level data as evidence, and developing recommendations to address the problem. Each MPC state published, disseminated, and championed mathematics pathways recommendations as an outcome of Phase 1.

The objective of creating the collective agenda was to build both urgency and motivation for change at scale. An immediate priority when creating a collective agenda is to bring stakeholders together to lead the work. Prior to the MPC project, the Dana Center's efforts to support state-level implementation had not prescribed the composition of the leadership team and its task force members. This had presented challenges in institutional representation on state-level task forces as one or more sectors of higher education were lacking, or one sector was unequally represented over another. Uneven representation by either two- or four-year institutions presented a challenge to state-level task forces as the overrepresented sector was positioned to dominate the collective agenda. Consequently, beginning with the MPC project, the composition of the state-level work group charged with creating the collective agenda intentionally included members from both two- and four-year institutions across the state, who were carefully selected to represent broad engagement of mathematics faculty.

In creating the collective agenda, it was also critical to define the problem and its underlying drivers that mathematics pathways would address, particularly in the context of the use of state- or system-level data as evidence of the problem. Collecting data to define and support the problem proved to be challenging for MPC states. Some states have a highly decentralized system of higher education governance in which two- and four-year institutions have high degrees of autonomy and are primarily linked by sector and disciplinary affiliations and/or local articulation agreements. Such loosely defined systems might collect and analyze their own data but rarely engage in organizing or sharing with others to garner a bigger picture of state- or system-level problems. Furthermore, mathematics pathways initiatives are relatively new systemic innovations that require in-depth analysis of data metrics that might not be a part of current data collection processes. These challenges often hinder the use of data across higher education ecosystems. However, ingenuity prevailed in Phase 1 of the MPC project as states' task forces looked at national data or data collected for other related initiatives (e.g., guided pathways) to help them define their problem (while also initiating improvements for future data collection activity).

Strategies, Successes, and Challenges of Phase 2 of the MPC Project

In Phase 2, extensive work across higher education ecosystems and stakeholder groups in the MPC states centered on creating an environment to support statewide implementation. Initial efforts focused on creating policy and practice conditions for statewide implementation. Most state-level task forces established working groups focused on specific areas (e.g., transfer and applicability, student learning outcomes, professional development) to plan and take action towards the state's recommendations (see Table 2). Working groups in the MPC states consisted of representatives of higher education stakeholder groups, and were charged with addressing the "nuts and bolts" of carrying out the recommendations related to higher education ecosystems. For example, in Arkansas, working groups were established to enact recommendations outlined in their task force recommendations report (Arkansas Math Pathways Taskforce, 2017).

Table 2. Arkansas working groups supported by the Dana Center

Working Group Purpose	Involved Higher Education Ecosystems	Stakeholder Groups
Transfer and Applicability	State, System, and Institution	Administrators, Faculty, Policymakers, and State Agency Staff
Multiple Measures	System and Institution	Administrators, Faculty, and Advisors
Faculty Professional Development	Institution and Classroom	Administrators, Faculty, and Advisors
Arkansas Course Transfer System (ACTS) Language	State, System, and Institution	Policymakers, State Agency Staff, and Faculty

A common challenge when coordinating long-term action across higher education ecosystems is burnout. Missouri—a state that had been supported by the Dana Center under the Building Math Pathways to Programs of Study (BMPPS) initiative from 2014 to 2016, and through the MPC project—faced this particular obstacle. During Phase 2 of the MPC project, both system- and institutional-level stakeholders across Missouri devoted countless hours to a multitude of tasks related to implementation of mathematics pathways, including up to eight task force meetings a year, active engagement in state- and institutional-level workshops, communication and engagement outreach, and multiple working groups. This level of active, long-term engagement with the MPC project led to positive results across the higher education ecosystem, but it also strained task force members. In order to combat burnout, the state intentionally divided its final year of activity under the MPC project into a regional approach so that institutions within each region would enhance their commitment, improve discussions among transfer partners, and equally distribute responsibilities for math pathways implementation.

Strategies, Successes, and Challenges of Phase 3 of the MPC Project

During Phase 3, responsibility for implementing mathematics pathways shifted from the state-level task forces to institutional leadership teams. Leveraging the action that had been taken in Phases 1 and 2, MPC state-level task forces secured institutional commitments (e.g., letters of commitment, memorandum of understanding) from institutional leadership teams that defined their roles and responsibilities for implementing the mathematics pathways. Securing early institutional engagement and commitment helped institutions gain equal access to resources, tools, and support (e.g., professional development, site visits). Although implementation responsibility shifted to institutional leadership teams during this phase, the state-level task force was still active and was charged with monitoring and supporting ***all*** public two- and four-year institutions through tiered engagement.

Tiered engagement is defined by two categories: early implementer institutions and late implementer institutions. In both tiers, resources, tools, and support were identified, defined, and prioritized to ensure that all institutions were able to engage in the MPC project in some manner. Table 3 identifies the tiered engagement and corresponding supports provided by the state-level task forces across the MPC states.

Table 3. Types of support for tiered engagement in mathematics pathways across MPC states

Types of Support	Offered to...	
	Early Implementer Institutions	Late Implementer Institutions
Professional development workshops (e.g., co-requisite, advising)	X	X
Site visits and/or 1-on-1 biannual leadership team calls	X	
Resources and tools to support institutional leadership teams, available from DCMP resource site	X	X
Regular communication and engagement of mathematics pathways activities	X	X

Note: Professional development workshops are tailored to support early implementer institutions and are offered to both early and late implementer institutions.

In order to initiate Phase 3 strategies, each MPC state hosted a Designing Mathematics Pathways workshop for all two- and four-year institutions regardless of their institutional commitment or designation to a tier-of-engagement for the MPC project. This initial opportunity empowered each institution to learn about the MPC initiative in their state and easily identify their institution's readiness to commit and the necessary resources to support its efforts.

Those MPC states that strategically engaged their institutions early in the MPC project experienced large-scale success in securing institutional comments and identifying tiered engagements. For example, in Phase 1 of the MPC project, Arkansas and Oklahoma, which were working independently, established their state-level task force memberships with representatives from all public higher education institutions in their respective states. This early state-level engagement, with representatives from all public higher education institutions serving on the task force, fostered success for both states to achieve their scaling strategy (in Phase 2) by gaining institutional commitments from most, if not all, two- and four- year institutions as early implementers in the MPC project. Across other MPC states, strategic recruitment efforts secured a cohort of committed institutions as "early implementers." For a list of MPC states' secured institutional commitments, see *Implementation Connect* (Charles A. Dana Center, 2018).

Strategies, Successes, and Failures of Phase 4 of the MPC Project

The final phase involves developing a sustainability plan in each MPC state that defines intentional structures (processes and strategies by both state- and institutional-level stakeholders) needed to sustain change at scale beyond the MPC project timeline (November 2018). This strategy of embedding structures for deep and sustained change at scale is crucial to move a pilot innovation to sustained practice. The outcome of Phase 4 is normative, sustained, and institutionalized practice for all students in a state and its higher education institutions with regard to mathematics pathways. Commitment to structures that would support the sustainability of mathematics pathways and change at scale was an initial and ongoing requirement for all MPC states. In the initial application process, states committed to the key sustainability of scale structures (see Table 4).

Table 4. Intentional structures for sustainability of mathematics pathways

Intentional Structures for Sustainability of Mathematics Pathways
• Establish a "home" for the work.
• Collaborate with policy agencies.
• Collaborate across two- and four-year institutions.
• Connect the work across developmental and gateway mathematics courses.
• Implement mathematics pathways based on the DCMP model.
• Cover costs to support project activities.

Not only were intentional structures embedded in the initial commitment to the project and throughout Phases 1–3, but they were also fostered in discussions to support self-funding beyond the project. This self-funding was secured through means such as legislative budget appropriations, higher education funding formula amendments, or reallocation of resources through institutional strategic plans. For example, Michigan secured legislative appropriations within its 2018 budget for an estimated $1 million dollars to support multiple mathematics pathways work by expanding the Michigan Transfer Network. This network is aimed to support faculty professional development opportunities, align mathematics courses to programs of study, and improve access to data across Michigan's institutions.

In the Fall 2017, Arkansas repealed its needs-based and outcome-centered higher education funding formula to a productivity-based funding model to align with statewide goals for higher education across two- and four-year institutions (Arkansas Department of Higher Education, 2017a, 2017b). Effectiveness, a dominant (80 percent) category of Arkansas's productivity-based funding formula, encompasses credentials, progression, transfer success, and gateway course success to include mathematics. The self-funding efforts of Michigan and Arkansas are establishing intentional structures for sustained change at scale for mathematics pathways.

The greatest challenge for Phase 4, which is yet to be realized, is enactment of sustainability plans over time and maintaining momentum beyond the scope of the MPC project.

Conclusion

Based on observations and experiences from the Dana Center's MPC project, important conclusions were made about the practicality of scaling the DCMP model beyond Texas, that is, the Dana Center's processes and strategies as developed in the DCMP theory of scale to support implementation and scaling of mathematics pathways in terms of breadth and depth to improve student completion. These conclusions are:

- ✓ The key to change at scale of mathematics pathways involves both reliable processes and strategies from the Dana Center and adapting support to each state's context.
- ✓ Empowering customization to local needs is essential to the sustainability of mathematics pathways (e.g., policy environment).

For the Mathematics Pathways to Completion project, successful state- and institutional-level implementation across Phases 1–3 involved using Dana Center processes and strategies, as well as the Center's resources, tools, and advisory support. At the same time, each state still retained a high level of autonomy and flexibility to implement mathematics pathways that were congruent with local contexts. As the Dana Center works across diverse higher education ecosystems and states, continuous improvement of its processes and strategies is a priority, particularly as the Dana Center learns from local leaders about how best to leverage local educational and policy environments to support the implementation and scale of mathematics pathways.

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Chapter 8

Counting on Our Future:

First in the World (FITW) Maryland Mathematics Reform Initiative (MMRI)

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Abstract

The Maryland Mathematics Reform Initiative (MMRI) is a collaborative effort between the public four-year University System of Maryland institutions and the community colleges in Maryland to develop and implement multiple, high-quality mathematics pathways. The focus is on the mathematics that is relevant for students' chosen career paths, while also ensuring that new courses have sufficient mathematical integrity and rigor to be deemed "college level." This chapter presents a case study of the MMRI and the state's efforts in undergraduate mathematics reform. The work in Maryland is presented chronologically and details the evolution of the state's mathematics goals and process for regulatory and policy change. The implementation of an ongoing postsecondary developmental pathways reform project is highlighted along with implications for other states and systems looking to make similar reforms.

Setting Maryland's State-Level Higher Education Mathematics Policies

Mathematics reform in Maryland is a process of continuous revision that requires consideration of all levels along the P-20 continuum, that is, education from pre-school through graduation and entrance into the workforce. The work in the state has historically considered evidence of need and responded with raised standards and changed policies. Current work to reform undergraduate mathematics is focused on postsecondary developmental-level coursework.

Completion of a college degree is associated with better economic, social, psychological, and medical outcomes than not (The College Board, 2013; Pew Research Center, 2014). Further, there is major cost savings potential for systems and states that reform postsecondary developmental mathematics. Mathematics success is linked to college success (Hagedorn, Cabrera, & Prather, 2010), and traditional developmental education, which entails a series of courses leading to and through algebra and calculus, is costly. Maryland community colleges spend about $7,000 per student for developmental education, and the University System of Maryland (USM) spends about $9,000 for each four-year student. Half of all USM students begin in community colleges, and 71 percent of Maryland's community college students test into developmental mathematics (Maryland Department of Legislative Services, 2012; Maryland Higher Education Commission, 2013).

Success in developmental coursework has implications beyond degree completion. The imperative to reform developmental mathematics is evident in recent research on enrollment patterns and college completion. Students from the lowest income quartile have less than an 8 percent chance of ever earning a college degree, while their wealthier counterparts have an 82 percent chance of completion (Lynch, Engle, & Cruz, 2011). The obstacle many of these students face is the need for remediation, often called developmental coursework, designed to remove deficiencies in mathematics knowledge and skills needed to be successful in college-level classes (Executive Office of the President, 2014; Rath, Rock, & Laferriere, 2013). Developmental coursework does not count toward degree completion, although enrollment usually costs the same and class attendance takes up the equivalent amount of time of a credit-bearing class (Knepler, Klasik, & Sunderman, 2014).

While research has shown developmental coursework to be "highly effective at resolving skill deficiencies," the "majority of remedial students do not remediate successfully" (Bahr, 2008b, p. 421). In fact, Bahr found that just one-fourth of remedial students move successfully to a college-level course, and one-fifth actually complete a credential or transfer. Further, students who were unsuccessful in developmental courses were unlikely to make long-term academic progress in general. Developmental mathematics has been identified as a dead end for the majority of students who test into it. Anthony Bryk of the Carnegie Institute for the Advancement of Teaching has called intermediate algebra the academic graveyard for non-STEM majors (Merseth, 2011). Indeed, just 27 percent of students enrolled in Intermediate Algebra ever complete a degree (National Center for Education Statistics, 2013).

In response to the challenges highlighted above, Maryland developed the goals for undergraduate mathematics below (Maryland State Department of Education, 2004). The remainder of this chapter discusses the origin of the goals, and expands upon our particular policy context and how leaders over time have grappled with "the magnitude of the change" (Berry, Ellis, & Hughes, 2014, p. 564) needed to have positive effects at the micro and macro levels. Policy takeaways that might be applied to other systems or states are also presented. This chapter shares the effort in Maryland to move from opportunities to new policy, to practice, and to a theory of action, to achieve the following goals for undergraduate mathematics:

1. to reduce the number of students taking remedial mathematics,
2. to increase the percentage of students who successfully complete remedial mathematics within their first year of college,
3. to increase the percentage of first-year freshmen who successfully complete a mathematics course that fulfills a general education requirement in their first year,
4. to develop mathematics pathways to place students in more appropriate courses for their educational goals and for success in their degree program area, and
5. to provide better advising for incoming freshmen and returning non-traditional students.

History and Context for Mathematics Reform in Maryland

Higher education mathematics reform in Maryland has a long history that began in the mid-1990s when the Statewide Mathematics Group (SMG), comprising college mathematics professors, reviewed K–12 teaching goals and noted gaps in content that inhibited students from being successful in college mathematics courses. In response in 1999, the Maryland State Department of Education (MSDE) tasked a collaborative group of secondary and college educators, called the K–16 Council, to oversee the development of *Bridge Goals*, mathematics goals that would bridge the gap between the state's *Core Learning Goals* and credit-bearing college mathematics goals (MSDE, 2004). The K–16 Council convened Bridge Goal Task Forces between 1999 and 2004 to study the links between secondary and college-level mathematics. Large-scale studies of student performance were conducted to determine the connection between high school, developmental, and credit-bearing mathematics courses. These studies confirmed the link between taking mathematics in the senior year of high school and students' success in the first college mathematics course in the following year. These findings, linking high school math-taking patterns to college success, have been echoed in many other studies around the country (e.g., Hagedorn et al., 2010) and had a direct effect on higher education policy in the state. Admissions standards for all University System of Maryland institutions were revised to require four years of mathematics in high school.

New Policy, New Opportunity

Building on the work of the state's mathematics community, Maryland's General Assembly passed the College and Career Readiness and College Completion Act of 2013, which formulated a coherent policy linking K–12 school reform with postsecondary student success (Maryland Association of Community Colleges, 2013). Under this landmark legislation, all public higher education institutions in the state must ensure that all enrolled students take their credit-bearing mathematics and English general education courses within the first 24 credit hours of study. In addition, institutions are required to ensure that students begin their developmental courses sequences, if applicable, during their first semester. In an effort to develop an implementation plan, representatives from Maryland's P–20 education sectors partnered to create a day-long conference in 2014 for faculty, K–12 teachers, administrators, and policy leaders to identify which quantitative literacy skills undergraduate students need for future success (USM, 2014). Dr. Uri Treisman, executive director of the Dana Center, delivered the keynote address and challenged education leaders to answer the question: "What does quantitative literacy mean for Maryland education and what systemic changes are needed?"

As a direct result of the 2014 conference, University System of Maryland Chancellor Dr. Brit Kirwan created the Maryland Mathematics Reform Initiative (MMRI), appointing a steering committee of mathematics experts to study national and state mathematics trends, initiatives, and data and make recommendations for necessary policy changes and future mathematics curricula in Maryland higher education. The intended outcome of the reform initiative was for Maryland institutions to design mathematics options that yield (a) increased success for students in the study of mathematics, (b) a higher percentage of students completing degree programs, and (c) effective transferability of mathematics credits for students moving from one institution to another. The steering committee was charged with developing student expectations and institutional processes.

The MMRI steering committee observed a significant, underlying problem with traditional developmental mathematics course sequences: the "disconnect" between the mathematics content students were learning in their general education mathematics courses and the mathematics students need to be successful in their majors. In fact, the state's former regulatory language identified college-level mathematics as "college algebra and above" (see Code of Maryland Regulations, 2017, Table 1). As a result, most institutions enrolled students in the intermediate algebra developmental sequence with the expectation that all students, regardless of major, would complete a calculus-based mathematics course to fulfill the general education requirement. The steering committee charged a workgroup of two-year and four-year mathematics faculty to revise the state regulatory language for general education mathematics to reflect a new understanding of quantitative literacy and allow for alternative pathways in mathematical education.

Table 1. Maryland state regulatory language on college mathematics

Old Language	New Language
One course in mathematics at or above the level of college algebra	One course in mathematics, having performance expectations demonstrating a level of mathematical maturity beyond the Maryland College and Career Ready Standards in Mathematics (including problem-solving skills, and mathematical concepts and techniques that can be applied in the student's program of study)

From Policy to Practice to Action: FITW MMRI

The MMRI continues as a collaboration between the public four-year USM institutions and the two-year community colleges in the state to develop and implement multiple high-quality mathematics pathways for students that are relevant for their chosen career paths while also ensuring that the new courses have sufficient mathematical integrity and rigor to be deemed college level. As part of the statewide MMRI steering committee work, the University System of Maryland applied for and was awarded a five-year grant in 2015 from the U.S. Department of Education's First in the World (FITW) program to develop, implement, and evaluate a statistics pathway to accelerate developmental students' progress into credit-bearing postsecondary courses and to help more of those students reach certificate or degree completion effectively and efficiently (United States Department of Education, 2015). Project goals are in support of the SMG's goals for undergraduate mathematics and include reducing costs for students who will not have to languish in developmental courses, and saving the state and higher education institutions at least a portion of the estimated $72 million spent annually in Maryland on developmental education (Alliance for Excellent Education, 2011). To meet those goals, the FITW MMRI program supports the development of a new developmental statistics pathway that leads to a general education statistics course. The 12 partnering institutions include five USM four-year institutions and seven two-year community colleges, serving approximately 158,000 new students each year.

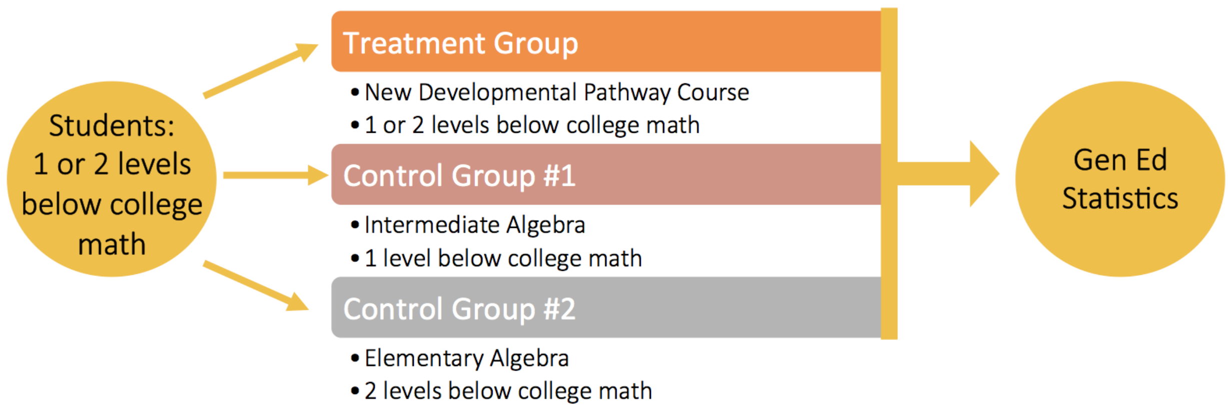
The FITW MMRI project is based on the same hypothesis that led to regulatory changes in the state's definition of general education mathematics: that there is a disconnect between the mathematics content students are learning and the mathematics they need to be successful. This hypothesis led to a holistic approach to reform developmental mathematics that addresses both the structural sequence and the content of the courses. This is a fairly new approach in that most reform efforts have focused either on redesigning course structure and sequence (Hanover Research, 2013; Twigg, n.d.) or on creating co-requisite developmental supports while students stay enrolled in college-level classes (Vandal, n.d.). The FITW MMRI's systemic approach is supported by research that states such is more likely to affect college completion rates than would reform of discrete programs or individual courses (Bailey, Jaggars, & Jenkins, 2015).

The key intervention in the project focuses on a rigorous pathway in statistical reasoning. In the FITW MMRI theory of action, the new pathway would be more appropriate, more relevant, and more useful for students who are either undecided about their major or whose college major relies on an introductory, credit-bearing statistics course either in place of, or in addition to a traditional college algebra course. The new statistics pathway is a single, intellectually rigorous developmental statistics course that meets the needs of students who may be one to two levels below college-level mathematics and for whom a calculus-based, college-level mathematics is less relevant to their intended major, followed by a college-level statistics course. The new statistics pathway is a strategy that would potentially reduce barriers (costs and time associated with taking multiple developmental-level mathematics courses) to college credit accumulation and successful completion of a postsecondary degree.

FITW MMRI Research Questions

One research goal for FITW MMRI is to determine the effects of a newly designed mathematics pathway on student rates of enrollment and success in a college-level statistics course, college retention, and persistence towards degree completion compared to a matched comparison group of students who take traditional developmental algebra courses (see Figure 1).

Figure 1. Developmental pathways for students: traditional vs. statistics pathway



The success of this new statistics pathway is dependent on a set of design elements that support creation of a new institutional infrastructure, supports for faculty teaching the pathway courses, and supports for students who are placed in developmental mathematics. The critical design elements include an institutional liaison, a mathematics content faculty fellow, an assessment faculty fellow, an advising liaison, and a data or institutional research representative for each partner institution. These elements represent what Bailey et al. (2015) referred to as holistic and broad-based participation in a pathways reform effort:

- *Institutional liaisons* serve as the institutional administrative leaders for the mathematics reform work and are responsible for coordinating all project activities on the campus. Specific duties of institutional liaisons include coordinating professional development opportunities for faculty.
- *Mathematics content faculty fellows* provide the academic and intellectual leadership for mathematics content and innovations in teaching.
- *Assessment faculty fellows* develop common summative assessment items that are used to validate the academic rigor of the new pathway.
- *Advising liaisons* serve the critical connection of the institutional advising community to the FITW MMRI pathway. Advising is particularly influential on developmental student success, especially for students aiming to transfer from one institution to another. Effective advising has been found to have a significantly positive effect on student persistence (Bahr, 2008b; Pascarella & Terenzini, 2005; Seidman, 1991), with more impact on students in need of remediation (Bahr, 2008a).
- *Data or institutional research representatives* are critical to ensuring that the project collects, protects, and maintains all data that are necessary to measure the overall impact of the new pathway on student persistence and graduation.

The impact of the FITW MMRI is currently being measured as the project is implemented across the state. This research will add to what is understood about the effects of the mathematics pathways on students' future academic performance. However, it is expected that findings will have implications beyond mathematics; anecdotal evidence shows the positive effects of changed pathways and changed teaching habits on student outlook. Our future research will focus on exploring how to sustain successful innovations despite challenges such as campus faculty and staff turnover, institutional administrative layers/bureaucracy, and severed or historically tense lines of communication between and within institutions.

Conclusion

At the writing of this chapter, FITW MMRI has completed its pilot implementation year and is beginning the first year of statewide implementation. During this short time, it has been concluded that to move large-scale policy into the implementation phase, policy and implementation work need to be grounded in the three key foundational ideas:

- common understanding of the problem(s),
- shared belief in the significance of the problem(s), and
- institutional leadership and faculty buy-in.

Of the three foundational ideas, strong institutional leadership and faculty buy-in are the greatest potential challenge. In Maryland, the mathematics faculty members have a long history of meeting and working together in open, frank discussions about higher education mathematics teaching and learning. Buy-in from this faculty group has been critical in moving the new pathway forward. The success of new mathematics pathways policies is also dependent on a state's or institution's capacity to provide resources for faculty, advisors, and other necessary support professionals to design, implement, and sustain the new pathway, while keeping the larger higher education community engaged in the progress of the work. Collective, collaborative action, informed by research on how students learn mathematics best, is Maryland's goal for the future.

Bringing together the entire mathematics community in the state of Maryland to focus on student success in mathematics and college completion is the main component of being First in the World!

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Chapter 9

The Grass Grows Green in Virginia:
A Grassroots Effort Leading to Comprehensive Change in Removing Mathematics Barriers for Students

Patricia M. Parker
Virginia Community College System

Abstract
The Virginia Community College System (VCCS) embarked on a comprehensive mathematics pathways project in October 2015 with a move from design to implementation in Spring 2017. The VCCS Mathematics Pathways Project (VMPP) aimed not only to develop strategies to improve retention and completion, but also to address foundational barriers to students' success. This grassroots effort involved collaboration among all 23 community colleges, over 200 mathematics faculty, and staff from career and technical support departments. Collaboration extended to the K–12 and university sectors, professional organizations, publishers, and foundations. VMPP goals focused on creating structured mathematics pathway courses for all program levels, implementing co-requisite opportunities for students, collaborating with K–12 and four-year institutions regarding mathematics readiness, developing multiple measures of placement, and improving Virginia's placement instruments. While the decisions made throughout this project were informed by research, the focus of this discussion is how Virginia's organization, processes, stakeholder collaboration, and communication laid the foundation to successfully implement this comprehensive project at scale.

Introduction

Institutions of higher learning across the country face a multitude of challenges in regard to student degree completion. One major barrier is students' completion of the required mathematics for their program of study. A number of states have been addressing these issues through a combination of structured pathways, co-requisite models, early collaboration with high schools, and/or improved placement practices. The Commonwealth of Virginia aspired to address these areas in a statewide remodel of its mathematics program using a representative workgroup model with strong communication. The success of this work depended heavily upon a consistent infrastructure that included structural organization and processes, plans for stakeholder involvement, plans for strategic and broad communication, and an aggressive timeline for implementation. As with any major project, reflection on the project provided great insight into what was achieved and what lessons were learned.

The Virginia Community College System (VCCS) embarked on a comprehensive mathematics pathways project in October 2015 with a move from design to implementation in Spring 2017. The VCCS Mathematics Pathways Project (VMPP) aimed not only to develop strategies to improve retention and completion, but also to address foundational barriers to students' success. This grassroots effort involved collaboration among all 23 community colleges, over 200 mathematics faculty, and staff from career and technical support departments. In sharing the activities, organization, and processes involved in designing and implementing a statewide initiative, this chapter seeks to provide guidance to other faculty, institutions, and policymakers in creating their own agenda and strategies for change.

A Case for Change: Virginia's Complete 2021

In Virginia, the 23 community colleges operate under one state system. Over the last 50 years, each community college has operated autonomously to meet their sister universities' and nearby workforce's needs, resulting in a repetitive and poorly defined master course file and inconsistency in transferability to the Commonwealth's 15 public and 24 private universities. As a result, advising students became almost impossible for colleges, leaving students to flounder in course selection, particularly in mathematics. In 2015, the VCCS Chancellor challenged the community colleges to triple the number of credentials completed by students attending its colleges. The new strategic plan, Complete 2021, focused on degree completion and better course options and selection to increase economic mobility and individual prosperity across the Commonwealth.

Success in mathematics is one of the biggest barriers to students' college completion (Complete College America, 2017). Virginia's data do not stray far from the national data indicating the same trends. In the VCCS, 37.7 percent of first-time-in-college (FTIC) associate degree-seeking students are placed into the lowest level developmental mathematics modules. Of these, only 14 percent complete a college-level mathematics course within four semesters. Only 14.5 percent of students taking any developmental coursework complete a degree or certificate within three years (State Council of Higher Education for Virginia, 2017). Success of the students in mathematics needed to become part of the solution to Complete 2021.

Mathematics faculty were called into action. Having identified student completion in mathematics as one of the biggest barriers to student success, the Chancellor challenged the mathematics faculty to be part of the solution. The charge was simply stated by the VCCS Assistant-Vice Chancellor: “We have a problem; help us fix this.” In Fall 2015, the VCCS mathematics faculty joined forces and over the next two years defined, designed, and prepared for implementation of the mathematics pathways project. A true grassroots effort, the mission of VMPP was to improve student success in developmental mathematics through gateway mathematics courses by reducing the time to completion with increased success and greater levels of rigor. Faculty designed, system supported—here is our story.

Laying the Groundwork: Getting Started

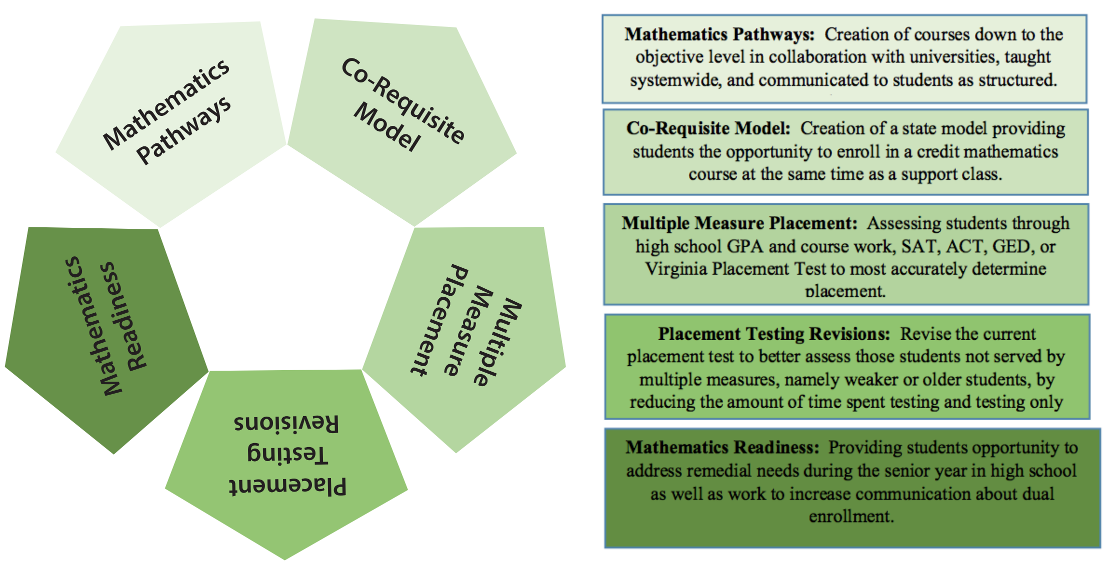
The process began in October 2015 with an all-day meeting, convened by the project manager, and included the VCCS Vice-Chancellor, the Assistant-Vice Chancellor, and two mathematics faculty representatives from each community college. After reviewing data, identifying specific barriers, and hearing college input, the mathematics faculty elected to engage in a comprehensive approach for change. The five goals developed at this meeting later paved the way for multiple solutions: Mathematics Pathways, Co-requisite Models, Multiple Measure Placement, Placement Test Revisions, and Mathematics Readiness (see Figure 1).

Over the first two years of the project (2015–2017), more than 200 mathematics faculty worked at the state level, countless others worked at the college level, and over 300 external stakeholders collaborated in the creation of strategies to address the five overarching goals. The design and implementation of a multifaceted, statewide project depended on the collaborative efforts of all stakeholders, a strong focus on common goals and outcomes, clear communication methods, and the commitment to project completion and its continuous improvement.

Organization and Processes

Creating an infrastructure that established clear and well-defined parameters about how contributors were organized and the structure in

Figure 1. VCCS Mathematics Pathways Project goals



which work would be done was critical to project success. Tools for communication and a timeline for work completion were the foundational pieces to all the processes that followed. For the VMPP work, electronic communication tools were used, instead of face-to-face meetings, so that faculty members could be involved and continue teaching their classes as scheduled. The use of an aggressive and realistic timeline optimized the motivation and appreciation of accomplishment of those involved. An ambitious timeline required thoughtful implementation, as such a timeline causes hardships for colleges where the culture of change is slow or where size dictates the speed of change. With these agreements in place, the work of dedicated people began.

Applying a comprehensive yet simple organizing plan to Virginia's work allowed for high levels of involvement and broad-based input from all math faculty. Organizers were also mindful of the need to accomplish tasks in a timely manner and to respect the fact that not all decisions would have full stakeholder consensus. The work of the VMPP was organized using multiple workgroups supported by a project manager. The project manager served as the organizing and convening chair of all major workgroups so that connections between the groups were facilitated since so much of Virginia's work overlapped in purpose and design. Each college identified its own local project manager, called a College Contact, who served as the lead communicator between the department and the VMPP project manager. Work on each of the five major goals was spearheaded by a VCCS workgroup consisting of 23 mathematics faculty—one from each community college—and the project manager. Workgroup members held the responsibility of engaging their faculty at the college level and representing their departments throughout the process. New course design was completed through smaller work teams, which consisted of some workgroup members and additional faculty. The addition of a sixth workgroup, Developmental Mathematics Leads, resulted in over 130 different voices involved in the initial conversation. To address areas outside of mathematics, such as necessary technical support, the application of focus groups provided opportunity for even greater collaboration.

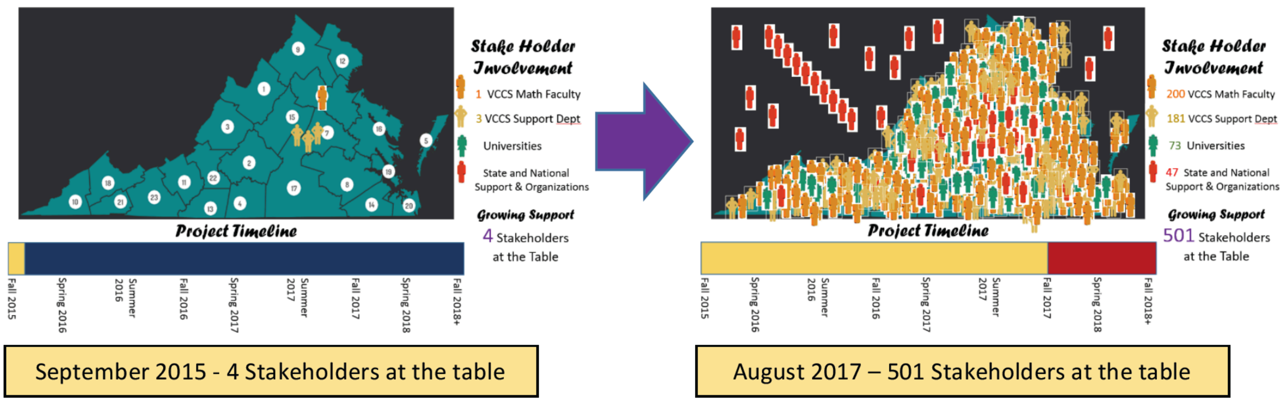
Establishing a positive atmosphere for productivity served as the final piece of an infrastructure that supported work completion. Setting parameters for engaging in that conversation resulted in all decisions being focused on what was best for the student in terms of successful completion, transferability, or entry into the workforce.

Stakeholder Involvement

High involvement of stakeholders was key. The identification and inclusion of stakeholders proved critical to moving the project forward. Having started with four stakeholders, the project expanded collaboration beyond the VCCS and state lines to learn from state and national work. The number of stakeholders quickly grew to 501, adding great value to the project (see Figure 2).

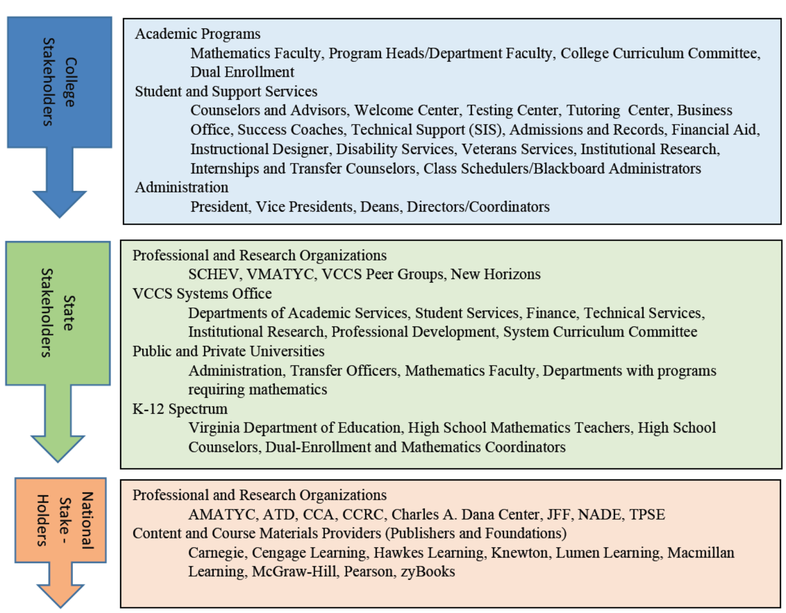
Although initial stakeholders included just the mathematics faculty, it immediately became clear that diversifying and involving others in the project was critical to its success. As the project grew, the outreach grew. Stakeholders were expanded to include community college- and system-level administrators, support staff, and faculty from other departments, state and national organizations working on support and policy around these initiatives, Virginia's public and private university transfer offices and academic departments, and foundations and publishers that provide support materials. Key to all of this collaboration was to involve each support group immediately upon identifying that either the project would impact their jobs, or their work was a key component to the success of the project.

Figure 2. Growing support: stakeholders at the table



Virginia experienced the most progress when a broad spectrum of faculty engaged with supporting departments and through the development and distribution of a second draft to the college contact or point person of each project component, giving opportunity for an additional level of feedback. Stakeholders responded favorably to early and frequent communication—evidence that their input was valued. As the project work developed, regular reflection on its future implementation and its potential impact on colleges, universities, workforce, and supporting companies helped to identify stakeholder groups that may have otherwise been overlooked (see Figure 3).

Figure 3. Stakeholder groups with Virginia examples



Communication

Having a clear communication plan from the beginning and being diligent in its execution were also critical to the project's success. With an underlying goal of keeping travel to a minimum, face-to-face meetings were reserved for the most important junctures of the project, leading to reliance on email, Google Docs, and web calls for most of the communication. Virginia's project applied these tools to achieve widespread and strategic email communication, seeking extensive feedback at both the college and individual faculty levels, or to ignite further action at the college level. Informational web calls reached all colleges to provide updates, entertain questions, and receive feedback, while working web calls focused on developing drafts, responding to feedback, and planning for implementation for various workgroups. Face-to-face meetings were key opportunities to achieve a high level of productivity and fulfill the need for all stakeholders to be in one place for collaboration and development. Virginia's two-year project utilized only five major face-to-face meetings and 14 university visits.

Sharing final documents through a public folder enabled all colleges to locate the most current version of a document and to collaborate with others. This folder was also shared with external stakeholders and interested parties.

Figure 4. Critical points – face-to-face communication

Fall 2015	October 2015 Kick-Off Meeting 2 Math Faculty/ College	May 2016 Math Summit 2-year & 4-year Faculty and VDOE	Summer 2016 Placement Test Rethink VPT Workgroup w/ Test Vendor	November 2016 Design to Implementation College Implementation Team	March 2017 Mathematics Pathways Institute and Publisher Showcase 6 Math Faculty/College	Fall 2017
	Monthly meetings with VCCS Assistant Vice Chancellors and Coordinators overseeing state-level departments related to project.					
	University visits initially involving a team of community college mathematics faculty and university mathematics faculty and evolving into expanded follow-up meetings including transfer directors and a variety of program heads.					

In all communication efforts, it was critical to be respectful of time limitations, have an established agenda shared prior to the meeting prompting college discussions, start and end on time, and monitor all written and verbal conversations to keep them focused on the goal of the specific conversation and/or the ultimate goal of the meeting.

Success at the Hands of Many

The significant effort of over 500 stakeholders resulted in specific strategies in the five project areas (see Table 1) to improve successful student experiences in mathematics. Some components and strategies were implemented statewide, while others remained at the discretion of the college. All were aimed at increasing the number of students earning a credential and moving successfully into the workforce or university.

Table 1. VCCS Mathematics Pathways project strategies

Mathematics Pathways	• Streamline and update the VCCS Master Mathematics Course File, creating consistency in course offerings across the VCCS. • Create structured mathematics pathways. • Align mathematics offerings, structured pathways, and degree requirements with university partners to improve transferability. • Reevaluate mathematics requirements for community college programs. • Communicate and discuss with K-12 the need for change at the community college level to better prepare students to meet the demands of universities and employers.
Co-requisite Model	• Identify mathematics courses and applied programs that are conducive to co-enrollment opportunities. • Develop a state model, related courses, parameters, guidelines, and promising practice recommendations.
Placement Testing	• Restructure the current Virginia Placement Test to address the changing profile of students testing, modify test length, and diversify question types.
Multiple Measure Placement	• Design multiple measure placement and support its implementation at all 23 colleges.
Mathematics Readiness	• Develop an understanding of current K-12 efforts for preparing students for mathematics readiness. • Develop a state model for collaboration between community college mathematics departments and high school mathematics departments for increasing the number of students entering the community college on level. • Develop a VCCS position on calculator use from placement to credit level courses and make recommendations on technology use based on university and workforce recommendations. • Develop conversation starts for dual-enrollment (DE) coordinators and faculty addressing challenges of DE programs.

We've Only Just Begun

The transition to implementation in late Fall 2016 sent colleges into a frenzy of planning. All colleges were challenged to implement all project strategies by Fall 2018 with about half of the colleges engaging in some level of early implementation in Fall 2017. The plan touched many areas of higher education from content design to pedagogy to counseling/advising to technical support. Few departments of a college were left unchanged. As Virginia headed into college-level implementation at each of the system's 23 community colleges, there was clear need for continued system-level support and future faculty engagement to maintain the vitality of this project. The types of support needed by the colleges to assure overall project success as a system include:

- Commitment to a continuous improvement model for all project strategies.
- Continued communication and collaboration between two-year and four-year institutions and among mathematics faculty.
- Implementation of assessment plans to track the impact of project components on student success.
- Development of a state-level structure for discipline-specific faculty leadership, by faculty for faculty.
- Greater attention on developing strategies and support that specifically help students of color who perform significantly lower in mathematics than white students.

Successes

In addition to meeting the Chancellor's charge by developing and implementing the strategies to increase student success, this project impacted Virginia more broadly than expected. Through the VMPP and the hard work of all its mathematics faculty and other stakeholders, Virginia has…

- Developed the VCCS Mathematics Pathways for Transfer that limits course choices while still meeting the requirements of students' programs and provides mathematics content directly related to future academic and career plans.
- Decluttered the VCCS Master Course File by replacing 61 loosely defined courses with 26 well-defined courses that were developed through collaboration between two- and four-year institutions.
- Improved the communication between Virginia Department of Education (VDOE) K–12 and postsecondary institutions, resulting in models developed for increasing mathematics readiness and increasing the dual-enrollment conversation as well as purposeful conversation around the use of technology in the mathematics classroom.
- Engaged in the development of the VCCS Multiple Measures for Placement and a renewed placement testing structure.
- Developed, piloted, and implemented a co-requisite model for all gateway courses, setting parameters and guidelines for colleges offering this option to students.
- Brought the national mathematics and completion conversations to Virginia for the first time by hosting a math summit that included mathematics faculty and representatives from Virginia Department of Education, Virginia Community College System, and Virginia public and private universities. This summit was co-sponsored by the State Council of Higher Education in Virginia (SCHEV) and the VCCS and highlighted the Charles A. Dana Center's Uri Treisman as the keynote speaker.

- Opened internal and external doors for purposeful conversation among K–16 faculty and institutions.
- Included the system's Developmental Mathematics College Leads in the conversation with the result of increased strategies available to colleges to best meet developmental student needs such as module-based instruction, core bundles, co-requisite courses, career and technical embedded courses, and high school mathematics readiness options.
- Experienced a faculty-grown, system-supported initiative.

Challenges and Lessons Learned

The project and its future are not without challenges and lessons learned. Most of the challenges centered on communication and in working with multiple institutions. Listed below are four items that may benefit others seeking to embark on statewide initiatives.

- **Beware of silos of communication:** The communication with and within each organization touched by this project proved to be isolated and not broadly shared. The assumption that one conversation would lead to many conversations was a false one. Requests for follow-up from individuals or institutions may spur broader conversations within the organizations.
- **Build consensus:** The initial success of this project depended on the consensus of many people from many different institutions. Perseverance and outreach by the project manager and other project champions often resulted in reaching a common ground.
- **Navigate systems:** When working with many organizations and institutions, navigating each system was time-consuming and challenging. Few organizations shared similarities in structure, persons of contact, or level of involvement. Patience and time conquered the challenge.
- **The ostrich effect:** Communication needed to be early and often, but messages and decisions were not always heard or received, causing implementation and change to be challenging. When stakeholders entered late into the conversation—most often after all decisions were made, implementation plans were in place, and the impact on the institution was established—it was important to acknowledge their concerns, remind them of the processes followed and the consensus reached, and patiently support them. Continued faith in the process was necessary.

The Virginia Mathematics Pathways Project is not the final step, but rather the first step in the right direction for supporting students as they challenge themselves to reach their goals. The project strategies, when coupled with initiatives such as Guided Pathways, Success Coaching, and advising restructuring, offer students better options for mathematics course placement and selection and can help maximize college completion. When the Virginia Community College System achieves its completion goal in 2021, it will embrace a new strategic plan. Students' success will be at the heart of its charge and its faculty will be ready to be a driving force to find a solution. Change driven by grassroots efforts is growing in Virginia. Other states have joined the national mathematics pathways movement. Virginia's grassroots efforts serve as a model to states aspiring to join the movement and drive change that is faculty led, administratively supported, and policy enabled.

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Resources

VCCS Mathematics Pathways Project: Collaborative Site. In addition to project documents, a research/resource folder contains many articles and data sources that provided a foundation for our conversations and influenced many of our decisions. www.tinyurl.com/VCCSMathPathways/

About the author

Patricia Parker served the Virginia Community College System (VCCS) as the VCCS Mathematics Pathways Project Manager and now serves as the Project Director for Transfer Virginia, a comprehensive transfer initiative for all of higher education in Virginia. Over the last 28 years, she served several institutions in the Commonwealth as a mathematics teacher, professor, and/or department chair. Her work with Virginia's 2012 Redesign of Developmental Mathematics, the Mathematics Pathways Project, and the current Transfer Virginia initiative have proven to be the most exhilarating and challenging aspects of her 28-year teaching experience. Her passion for engaging others in positive change has served her well in helping the Commonwealth of Virginia reach its ambitious goals.

Chapter 10

The Case for Mathematics Pathways from the Launch Years in High School through Postsecondary Education

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Abstract

Students are often "misprepared" for the mathematics they will need to take in college. Mispreparedness is the misalignment of math course-taking requirements and student aspirations. This chapter examines the changing definitions of college readiness and practices in higher education mathematics that have a positive impact on student completion. It synthesizes this knowledge into four recommendations for K–12 districts, in partnership with higher education, that will improve student preparedness for college.

Background

Success in mathematics courses is essential to college completion and career preparation. The definition of "college ready in mathematics" has been evolving to better reflect what mathematics students need to know and be able to do to be successful in their postsecondary aspirations. Too often, there remains a disconnect between course-taking requirements and content relevance in states' graduation requirements as compared to the preparation students need to be successful in their first college credit-bearing course. Students are often misprepared for the mathematics they will need to take in college.

This chapter explores the impact of mispreparedness on students, where we define "mispreparedness" as misalignment of mathematics course-taking requirements and student aspirations. The chapter also examines the changing definitions of college readiness and practices in higher education mathematics that have a positive impact on student completion. It synthesizes this knowledge into four recommendations for K–12 districts, in collaboration with higher education systems, to improve student preparedness for college.

The Mathematics Launch Years Toolkit consists of briefs intended to support districts and higher education systems in streamlining the transition for students from high school to college. The "Mathematics Launch Years" in high school refer to the content that follows the foundational algebraic and geometric thinking usually located in Algebra I, Geometry, and parts of Algebra II courses. In Launch Years courses, students can explore mathematics pathways aligned to their postsecondary programs of study and career aspirations.

The definition of mathematics college readiness is evolving.

Historically, College Algebra was intended to prepare students for Calculus, but in many postsecondary institutions, the course was treated as preparation for the majority of degrees. It became the default mathematics requirement for 80 percent of academic majors. However, most students do not need an algebra-intensive curriculum or Calculus to excel in their degree programs (Burdman, 2015). In 2004, the Mathematics Association of America (MAA), citing this serious mismatch between the original rationale for College Algebra and the mathematical needs of students who take the course, called for the end of College Algebra as a terminal mathematics course for graduation (MAA, 2004).

The recognition that College Algebra is not an appropriate default gateway course has since gained traction, culminating in a recommendation in 2015 from the MAA, along with four other major mathematical professional associations: the American Mathematical Association of Two-Year Colleges, the American Mathematical Society, the American Statistical Association, and the Society for Industrial and Applied Mathematics. These esteemed organizations reinforced MAA's recommendation, calling for implementation of multiple mathematics pathways aligned to fields of study, some of which should include early exposure to statistics, modeling, and computation (Saxe & Braddy, 2015). Colleges and universities across the country have begun to respond to this call by implementing and encouraging enrollment in mathematics pathways, such as quantitative reasoning, statistics, and the pathway to Calculus (or STEM pathway). Many of these initiatives include a redesign of traditional algebra-intensive programs.

High school graduates who are misprepared for college mathematics have only a small chance of earning a postsecondary certificate or degree.

The expectation of Calculus-only preparation is firmly rooted in K–12 districts, creating a problem similar to the one in higher education in which students are put on the path to Calculus regardless of its relevance to their programs of study. Students' lack of opportunity to engage with mathematics that matters to them is one of the factors resulting in a reality in which an estimated 60 percent of incoming two-year college students are placed into at least one developmental mathematics course each year (Bailey, Jeong, & Cho, 2010). Developmental mathematics is a course or sequence of courses students pay for at the college for which they do not receive college credit.

Historically, developmental courses on higher education campuses have had low success rates. National data show only 21 percent of students referred to remediation at a two-year college complete a "gateway" college mathematics course within two years. A gateway course is the first course that provides transferable, college-level credit allowing students to progress in their programs of study. When disaggregated by ethnicity and income, the disparity is troubling. Only 11 percent of African American students and 19 percent of Pell grant recipients referred to developmental courses in mathematics earn college credit in a mathematics course within two years (Complete College America, 2016). In addition to low success rates, these courses present an unnecessary hurdle for students whose programs of study do not actually require the specific content knowledge taught in those courses.

Increasing the number of high school graduates who are ready for college is a moral imperative with significant equity implications. The challenge is to increase the opportunity for students graduating high school to smoothly continue their growth as a learner and doer of mathematics in college. With increased and relevant course-taking choices in postsecondary institutions, course offerings in high schools need to adjust accordingly. Districts should re-examine how they can systemically and equitably provide relevant course offerings, additional supports for students, effective advising practices, and teaching practices that ensure students are developing capacity as learners and have a sense of purpose when they engage with mathematics. Solving the mathematics alignment challenge between K–12 and higher education is essential to preparing a more diverse student population for a successful college transition.

Evidence of Mathematics Pathways Success

The movement for mathematics pathways has been gaining traction. In Fall 2015, 58 percent of two-year colleges in the U.S. had implemented a pathways course sequence (Blair, Kirkman, & Maxwell, 2018). Students enrolled in institutions embracing this movement are benefiting from the increased focus on program-specific mathematics preparation and are more likely to succeed (Rutschow & Diamond, 2015). Examples of program-aligned mathematics pathways include a statistics course for a social science major or a rigorous quantitative reasoning course with real-world mathematics applications for an English major. Emerging evidence shows the benefit of mathematics pathways reform. In 2014, The University of Texas at Arlington began shifting enrollment from College Algebra to the mathematics courses required for students' majors. Between 2012 to 2015, the success rates for UT Arlington's students increased in all gateway mathematics courses, including College Algebra, between 5 and 16 percentage points (Banda, 2017).

Research by MDRC found that students enrolled in the Dana Center Mathematics Pathways (DCMP) statistics pathway experienced higher engagement and achieved higher pass rates compared to those enrolled in traditional algebra-intensive mathematics courses (Rutschow & Diamond, 2015). The MDRC report stated *three* times as many DCMP students completed a gateway mathematics course in one year as compared to traditional mathematics sequences. Further, five times as many DCMP students completed a gateway mathematics course in one year for those enrolled in back-to-back mathematics courses. Students reported being "surprised by how relevant math could be to their lives and how they could more critically evaluate everyday quantitative information . . . . Many had started in the DCMP classes feeling they could never grasp math, and many left . . . more confident in their ability to approach the quantitative issues they face in their everyday lives" (Rutschow & Diamond, 2015, p. 53). The combination of taking mathematics courses with examples set in relevant, real-world contexts and embedded social and emotional supports, such as learning about malleable intelligence and effective study habits, proved integral to students' success in those courses. These promising results underscore the need for studies to demonstrate these effects at larger scales.

Recommendations for a Mathematics Transition from High School to Postsecondary Education

The Dana Center makes the following recommendations to support students' seamless transition from K–12 to postsecondary institutions. These recommendations are directed to K–12 leaders although this work requires collaboration with, and leadership from, higher education.

1. **Collaborate with postsecondary partners to align expectations for the mathematics launch years courses in high school to the mathematics pathways movement in higher education systems in the region.**

   The articulation of higher education mathematics pathways with the mathematics launch years courses—when supported with quality instructional resources and well-prepared teachers—will improve students' postsecondary access and attainment. The brief *K–12 and Postsecondary Collaboration to Improve Mathematics Course Alignment: Recommended Process and Case Studies* (Charles A. Dana Center, 2018) outlines successful collaboration efforts across the education continuum to align mathematics expectations. As part of the Mathematics Launch Years Toolkit, the brief recommends involving policy stakeholders, identifying key K–12 and higher education leaders and structures, and using data to identify one galvanizing charge.

2. **Require four years of mathematics for high school graduation and encourage students to enroll in courses during all years of high school.**

   All high school students should take college-aligned, demanding mathematics each year to increase their chances of entering college prepared for college-level courses. In a study across three states of students who took the American College Test (ACT), 74 percent of those who had completed at least Algebra I, Geometry, and Algebra II moved directly into college-level, credit-bearing courses. The percentage increased to 83 percent for students who took an additional fourth year of advanced mathematics in high school (ACT, 2007). Students' mathematics launch years courses in the latter part of high school should finalize their preparation so they can progress directly into college-level mathematics courses.

3. Support all students in choosing which mathematics launch years courses to take based on their areas of academic, personal, and career interests.

High schools have the opportunity to expand mathematics preparation beyond the well-trodden, narrow path of Algebra I–to–Calculus sequence to include the diverse domains of mathematics students may need for their postsecondary degrees. All students need a foundation of essential algebraic, function, geometric, probabilistic, and statistical concepts, which are usually found in high school Algebra I, Geometry, and parts of Algebra II courses. The launch years of high school mathematics should offer a range of advanced high school and entry-level college mathematics courses that prepare students for the variety of mathematics pathways and career programs they will encounter in college. Courses that include applied algebra and statistics content cover a broader range of skills and critical thought processes appropriate for many fields of study. For example, when students encounter data and statistics, these courses teach students how to evaluate the validity of the information, draw conclusions, and strategically problem-solve.

By the fourth year of high school, many students are prepared to take foundational college-level mathematics courses through Advanced Placement (AP), International Baccalaureate, and other dual credit options. Some students may not yet be deemed college ready and can instead complete a college mathematics transition course. K–12 school districts and local institutions of higher education should begin or continue working together when choosing or developing fourth-year mathematics course options to confirm alignment to mathematics pathways in higher education.

The following options provide the opportunity for all twelfth graders either to finish preparing for college-level mathematics or to take the mathematics courses aligned with their programs of study. All courses should be demanding enough so students can move between the different mathematics pathways if they change to a new program of study that requires a different course sequence.

Programs of Study Requiring Algebra-Intensive Mathematics: The traditional Pre-Calculus and AP Calculus pathway is intended for individuals who are considering pursuing algebra-intensive majors in fields such as physical science, mathematics, biological science, computer science, engineering, business, or agriculture (Chen & Soldner, 2014). These majors typically require mathematics content that includes conceptual understanding, along with high levels of computational facility with algebraic and trigonometric expressions and functions. This content is covered in high school and college-level algebra and pre-calculus courses.

Programs of Study Requiring Non-Algebra-Intensive Mathematics: For students potentially interested in fields that do not require extensive knowledge of algebraic computation, other fourth-year mathematics course options—many of which are offered for dual credit—provide quantitative preparation more relevant to students' career aspirations. Statistics or quantitative reasoning courses taken after successful completion of Algebra II or an equivalent course are intended for the large population of students pursuing degrees in fields such as the allied health sciences, public safety, or the liberal arts and social sciences (Cullinane & Treisman, 2012).

4. **Identify students who are not ready for credit-bearing college mathematics by the end of their junior year and offer a twelfth-grade mathematics transition course.**

High school students who need additional algebraic reasoning, statistics, and quantitative skills can benefit from enrolling in a transition mathematics course in their senior year. Twelfth-grade transition courses in mathematics are available in a growing number of states across the country including Florida, Illinois, New Jersey, New York, Tennessee, Texas, Ohio, and West Virginia (Community College Research Center, 2016). These intervention structures identify students who are not college ready in mathematics by the end of eleventh grade, and require or encourage these students to take transition mathematics courses to build quantitative reasoning skills before they graduate from high school. Another brief from the Mathematics Launch Years Toolkit discusses transition courses more deeply. The Dana Center's *Defining Content in a Transition to College Mathematics Course at the Regional or State Level* (2018) presents strategies for working across stakeholder groups to define mathematics content and includes a case study of this process in Texas.

Conclusion

Students' success in college is greatly influenced by the mathematics they learn, how they learn it, and how they see themselves as a learner and doer of mathematics. It is time to better align the mathematics courses and expectations from high school to postsecondary education. The four recommendations in this chapter offer K–12 districts and higher education systems a place to start thinking about how they can tackle this work and alerts postsecondary education institutions and other stakeholders of the importance of aligning courses, programs, and systems to maximize student success.

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Section 3

State and Institutional Policy Enabled

Chapter 11

The Missing Piece:

The Transfer and Applicability of Mathematics Pathways

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Abstract

The lack of predictable transfer policies between institutions and the inconsistent applicability of mathematics credits across departments and programs of study are significant barriers to student persistence and completion. While many states have policies designed to facilitate student transfer, they are not always used, not uniformly applied, and often prove to be ineffective in helping students advance to degree completion. Moreover, state policies typically focus more on the issue of student movement between institutions and programs of study in terms of the *transferability* of courses from one institution to another rather than the *applicability* of credits to a student's chosen program of study—even though both transfer and applicability are equally important.

Unlike the more widely understood idea of transfer and articulation, in which institutions are the unit of measure and medium for change, transfer and applicability is a student-centered approach of ensuring that mathematics pathways are properly aligned with academic and career interests. The purpose of this chapter is to examine how one emerging policy issue in the mathematics pathways movement—the transfer and applicability of mathematics credits—has the potential to positively impact student success and social mobility. This chapter discusses past approaches, current barriers, and emerging strategies related to the transfer of mathematics pathway courses and the applicability of mathematics credits to ensure that a student is provided the opportunity to take the right mathematics at the right time, from admission to completion.

Introduction

According to a Community College Research Center (CCRC) report from 2015, even though 80 percent of community college students intend to transfer to a baccalaureate institution, only 25 percent of those students make the transition to a four-year institution within five years, and only 17 percent earn a bachelor's degree within six years of transferring (Jenkins & Fink, 2015). A more recent study from CCRC and the Aspen Institute noted that of the 720,000 degree-seeking students who enrolled in a two-year institution in Fall 2007, only 14 percent transferred to a four-year institution and graduated by Spring 2015 (Wyner, Deane, Jenkins, & Fink, 2016). The outcomes are even more troubling for students of color. A 2016 report from Education Northwest found that over 80 percent of Black and Latino community college students intended to transfer, but only 20 percent did so within six years of enrollment and less than 10 percent ever completed a bachelor's degree (Hodara, Martinez-Wenzel, Stevens, & Mazzeo, 2016). Stated simply, current approaches to student transfer and persistence do not serve students well and these same students are paying the price in more ways than one.

The misalignment of requirements between the two-year and four-year sectors, and the inconsistent applicability of credits upon transfer is an often overlooked issue regarding successful student transfer. This misalignment and unpredictability lead to either the loss or the unnecessary accumulation of credits when courses taken at the two-year level do not apply to a student's chosen field of study at the four-year level. In fact, it is the applicability of credits (i.e., the acceptance of credits, particularly mathematics credits, to a student's chosen program of study) earned at the two-year level that pose one of the greatest challenges to successful vertical student transfer (two-year to four-year) and bachelor's degree completion.

Implementing multiple mathematics pathways that include quantitative reasoning, statistics, and calculus that are more closely aligned with student interests and goals is an increasingly important strategy in addressing student persistence and completion. As explained in a 2016 "Call to Action" from the Charles A. Dana Center, "Traditional entry-level college mathematics fail to serve students well because they are structured as disconnected courses whose content is misaligned to students' career and life needs" (Getz & Ortiz, 2016, p.1). Mathematics pathways need to support student academic and career goals, and address the alignment of mathematics requirements between the two- and four-year postsecondary sectors.

Education stakeholders need to ask and answer two fundamental questions as they look to implement, scale, and align multiple mathematics pathways with student interests and specific programs of study: (1) Are community college students taking the right math at the right time—that is, are they taking courses and sequences that will apply to and be accepted by their chosen field of study and future career interests? (2) Is mathematics a barrier to student transfer to a four-year institution and completion of a baccalaureate degree?

Stated simply, transfer and applicability refers to the way course credits move from a sending institution and apply to degree requirements at a receiving institution. In the context of the Dana Center Mathematics Pathways (DCMP), applicability denotes a *student-centered* process to ensure that academic pathways (such as mathematics) are properly aligned with students' academic and career interests and that credits consistently apply to their chosen programs of study. Whereas past policy approaches have primarily stressed the *transferability* of credits between institutions, the emerging issue—

and one that needs greater attention from policymakers and other key education leaders and stakeholders—concerns the *applicability* of mathematics credits between departments and programs of study. This chapter will argue the case for moving beyond the common understanding and approach of transfer and articulation—which centers primarily on agreements between institutions or systems—and make transfer applicability—which centers primarily on student needs and goals—a priority.

Transfer Policy and Practice

Policymakers at the state and system levels have developed a variety of common policy solutions to ensure smooth and efficient transfer, and include (Education Commission of the States, 2016):

- **Common course numbering:** Sixteen states use common course numbering systems with the same course titles, descriptions, and identification numbers for comparable courses at all public institutions within a state, thereby helping to eliminate any confusion about the transferability of students' lower-division coursework.
- **Transferable lower-division core:** States, systems, or institutions can determine what constitutes a common general education core of classes in order to help two-year students automatically transfer their lower-division credits to a four-year institution. Thirty-six states allow for a transferable lower-division core of general education courses.
- **Guaranteed transfer of an associate's degree:** Thirty-two states guarantee junior standing at a four-year school to a student who earns an A.A. or an A.S. degree at a community college.
- **Course equivalency guides and transfer websites:** Twenty-four states have created online resources to help students understand how credits completed at their community college will align and apply to their major at the four-year institution.

Additionally, recent studies have shown that other factors can positively impact student transfer (Bailey, Jenkins, Fink, Cullinane, & Schudde, 2017;Wyner et al., 2016):

- **Declaring a major before transferring:** One predictor of possible student success post-transfer is the declaration of a major before making the move from a sending to a receiving institution. Declaring a major while still enrolled at the two-year level allows a student to take the appropriate courses before transferring to a four-year college or university.
- **Ensuring advisors are adequately trained:** In order to properly communicate information about mathematics pathways to prospective transfer students, advisors need to understand the possible pathways to choose from, how they align with student goals, and how to navigate students through the successful completion of a bachelor's degree.
- **Making transfer part of the institutional mission:** Dedicating resources and staff to deal directly with transfer students and making them a priority can create efficient and predictable pathways.

While policymakers at the state and system levels have developed approaches to ease the transfer of general education courses, the approaches have been less successful in addressing completion of specific degree requirements and the consistent applicability of credits to specific programs of study. In other words, applicability remains the missing piece.

When considering the common policy solutions related to student transfer listed above, the barrier of applicability becomes more apparent. Comparing policy to practice in each of those areas reveals ongoing challenges:

- A 2017 study about community college transfer in Texas argued that "[w]hile common course numbering might reduce confusion and the information burden for students and registrars, it still [does] not address the problem of the applicability of courses to a student's major or program of study" (Bailey et al., 2017, p. 7). The same study further pointed out that "even community college students who complete Texas's 42-credit general education core may find that these courses may not meet general education requirements for particular majors at a four-year college. As a result of this misalignment, students must in effect retake lower-division general education courses to satisfy bachelor's degree requirements" (p. 5).
- A 2016 study about tracking transfer outcomes in states concluded that the "connection between earning a community college credential before transferring and the probability of earning a bachelor's degree is not clear in most states," including Kansas, Maryland, Tennessee, and Texas (Jenkins & Fink, 2016, p. 6).
- A 2012 College Board report asserted that statewide articulation agreements have shown no impact on transfer rates at all (Handell & Williams, 2012).
- In the case of course equivalency guides or transfer websites, the burden for navigating the complex maze of requirements is often placed solely on students, many of whom are ill-equipped to understand exactly how their courses align with their intended fields of study.

Applicability: The Missing Piece

According to recent research, the largest barrier to completion of a bachelor's degree for community college students was the loss of credits upon transfer. For example, a 2014 study found that less than 60 percent of transfer students were unable to transfer a majority of their credits and that 15 percent were unable to transfer *any* of their credits at the community college. Essentially, one in seven students started the bachelor's degree as a freshman upon entrance to the receiving institution (Monaghan & Attewell, 2014).

The accumulation of excess credits can have the same negative effect on student persistence and completion. According to a 2011 study conducted by Complete College America, students who graduated from public four-year institutions in the U.S. earn an average of 14 percent more credits than are required to graduate and some earn up to 50 percent more credits than are needed (Complete College America, 2011). A 2013 study from the Edunomics Lab at Georgetown University stated, "These excess credits drive up cost per degree, when they are subsidized by public funds; leave fewer spots available for other students; and can slow or inhibit degree completion, given the fact that more credits equals more time and tuition for students" (Kinne, Blume, & Roza, 2013, p. 1).

As CCRC and the Aspen Institute made clear, "statewide general education agreements generally do not specify which courses can satisfy requirements for specific majors. This is particularly problematic for students seeking to enter majors in fields that have specific lower-division mathematics and science requirements, like business, nursing, and STEM" (Wyner et al., 2016, p. 50).

One example of the applicability problem is a student who takes a quantitative reasoning course that satisfies a mathematics requirement at the two-year institution because it aligns with their desire to become a historian. The receiving institution may accept the credits, but the specific requirements for a degree in history at the receiving institution call for college algebra instead of quantitative reasoning or statistics. Another example is a community college student seeking to pursue a degree in psychology who is faced with multiple and conflicting requirements at the four-year level, with some institutions requiring statistics, others requiring college algebra, and others requiring no college-level math at all. This unnecessary, but all-too-common scenario demonstrates just how complex and confusing the transfer process can be for students, particularly low-income or first-generation students who might not have the resources or support to navigate the maze of requirements.

Focusing exclusively on general education agreements or a transferable core of courses fails to address the more complex issue of major requirements. Likewise, placing the burden of navigating transfer portals or course equivalency databases solely on students can lead to confusion and inappropriate course selection. Several of the “top” fields of study such as Business, Nursing, Engineering, and Education have very specific—and often very different—lower-division mathematics requirements. A “one size fits all” approach simply does not work.

The Right Math at the Right Time: Recommendations

With these challenges in mind, the time has come for stakeholders at the state and system levels to look beyond common policies in order to more fully address the applicability issue. In particular, consistent and predictable transfer and applicability of mathematics credits between institutions and programs of study are important for students in mathematics pathways.

Two- and four-year institutions and systems must work in concert with state agencies, policymakers, and other key stakeholders to turn proposed policy into effective practice. Recommendations and successful initiatives include:

- **Collecting comprehensive data** related to total student transfer by major, the most in-demand programs of study, and how mathematics requirements align and credits apply across the postsecondary sectors can help states positively impact transfer pathways for the greatest number of students in the short term and create a foundation for future efforts related to other disciplines. The Oklahoma State Board of Regents has taken the first steps towards understanding student pathways and persistence by creating a framework capable of establishing baseline data and tracking a student’s progress across the higher education pipeline to determine if they are taking math courses that appropriately correspond with their academic interests and whether those credits are being applied to their programs of study.
- **Developing major-specific program maps** between institutions that specify mathematics requirements is critical to successful transfer and persistence. Legislators in Missouri passed a “Guided Pathways to Success” pilot program in 2016 that includes degree-based transfer pathways and the utilization of meta-majors to “minimize the loss of credit due to changes by students in their degree majors” (Missouri S.B. 997, 2016, 19). The Tennessee Transfer Program is another example of this approach. According to the National Conference of State Legislatures (NCSL), the program “lists all the courses necessary to earn an associate’s degree at a community college. When a student takes those courses and transfers to a four-year college or university, the transcript will indicate that the pathway has been followed. The student then

is guaranteed that all the community college courses will count toward completion of a bachelor's degree in the designated major" (Bautsch, 2013, p. 3).

- **Developing policies that offer more than helpful guidance**, but instead require increased student supports and adequate funding, in addition to legally binding accountability measures and deadlines to complete the work will help address the issue of transfer and applicability. In Missouri, the passage of its guided pathways legislation (Missouri S.B. 997, 2016) demonstrates the first step in addressing the transfer and applicability problem in the state.
- **Understanding how state policy aligns with institutional practice** may help to identify additional disconnects and barriers that students face when trying to move between institutions. Determining if there are additional institutional requirements or examinations that lead to unnecessary loss of credits or improper placement at the receiving school can allow stakeholders at the institutional, system, and eventually state levels to address and rectify these issues. A transfer and applicability working group in the state of Washington is currently reviewing its statewide Direct Transfer Agreement degree in order to determine how the transfer math requirements specifically align with the requirements at the individual four-year institutions once students select a degree program and if the credits they took in community college apply to those degree programs.

These initial, isolated state policy efforts are a good start; however, the applicability issue remains mostly unaddressed in the vast majority of states. States involved in the Dana Center's Mathematics Pathways to Completion (n.d.) project have begun investigating and developing strategies, including the creating data templates capable of tracking student course-taking patterns, developing student transfer maps, and establishing regional partnerships between two-year and four-year institutions. States are gaining a better understanding of how mathematics credits transfer from two- to four-year institutions in specific programs of study. States are focusing their initial efforts on activities that are targeted and realistic. Understanding the issues between specific programs and institutions, as well as within specific regions, can help policymakers and practitioners develop larger and longer term, statewide strategies and solutions.

Conclusion

The work of implementing multiple mathematics pathways in the states is just beginning. There is still much to learn as the process moves forward, but one issue is clear: Moving from an understanding of transfer and *articulation* to a fuller understanding of transfer and *applicability* allows states, systems, and institutions to focus on the student needs first and foremost.

When developing ways to address transfer issues and implement multiple mathematics pathways in the states, policymakers and education practitioners must maintain an equal focus on the transfer *and* the applicability of mathematics credits. Education stakeholders in the states who are in a position to address issues related to transfer and applicability can and should focus on expanding and improving data collection that identifies transfer gaps, establishing program maps that foster coordination and develop a common language between institutions, and creating new ways to measure student progress and success as students move from one level to the next.

Ultimately, the goal is for individual efforts at institutions or within systems to stimulate collective action that leads to the development of eventual statewide solutions and to ensure that all mathematics pathways are aligned. The goal includes having courses and credits that are not only accepted but also applied across all institutions and disciplines. Implementing and scaling mathematics pathways that are both transferable between institutions and applicable across disciplines will enhance student persistence and boost completion rates throughout the country, improving social mobility for individual students and economic productivity for an entire state.

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Chapter 12

Why Placement Based on Algebra Doesn't Add Up

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Abstract

Traditional college algebra placement policies, which too often rely on a single score that is generated from a computer-adapted placement exam to assess a student's ability to succeed in a course, have recently come under scrutiny for misplacing students and leading to unnecessary remedial coursework. Recent research studies demonstrate that algebra skills alone do not predict success in college-level mathematics and persistence toward a degree. To address the situation, educational institutions around the country are adopting mathematics pathways models. Pathways curricula provide students with mathematics content that is relevant to their major fields of study and eliminate a long, prerequisite developmental course sequence. This chapter presents evidence that placement in remedial/developmental algebra does not lead to student success in college courses or graduation. It then reviews placement practices that better assess students' knowledge and experience for predicting success in their chosen major fields of study. Finally, the chapter argues that students, along with the guidance of trained advisors, should advocate for their own placement through a holistic assessment of their skills, abilities, and career aspirations.

Introduction

Higher education policymakers, leaders, instructors, and students around the country bear witness to the serious scrutiny and criticism that college mathematics placement policies have experienced over the last decade. This scrutiny derives from awareness that approximately 60 percent of incoming community college students are placed—by subject experts—into developmental mathematics coursework that is meant to provide them with the necessary preparation for success in college (Bailey, Jeong, & Cho, 2010; Complete College America, 2012). However, it has become clear that these traditional placement practices not only place some students into developmental courses that are misaligned with their desired fields of study, but they also start many students on a long sequence of possibly irrelevant coursework. Because of this misalignment, students often leave college with a large student debt and/or without their college degree and gainful employment to help pay off that debt.

Students have the greatest likelihood of success in college when their mathematical capabilities are assessed more accurately by the use of multiple placement criteria that relate to their major fields of study (Ngo & Melguizo, 2016; Scott-Clayton, Crosta, & Belfield, 2014). While proficiency in algebra is essential for students whose program path eventually requires calculus, for students needing quantitative reasoning or statistics courses for their fields of study, the traditional assessment of algebra skills for placement purposes often leads to remedial coursework that is unnecessary. Mathematics pathways programs, in contrast, provide students with a sequence of mathematics courses that are relevant to their fields of study and which require no more than one semester of developmental coursework. This chapter will examine the current state of college mathematics placement policies, highlight studies to show why these policies need to change, and suggest more effective placement strategies to place students in shortened, relevant mathematics pathways programs.

What Do Mathematics Placement Tests Really Assess?

Traditional college mathematics requirements are built on a strong foundation of algebra. For example, many colleges require completion of an intermediate algebra course prior to enrollment in a college-level algebra or statistics course and proficiency in basic algebra for a college-level, liberal arts mathematics course that focuses on quantitative reasoning. With these policies, contemporary mathematics placement tests attempt to predict how well a student is expected to perform in a developmental algebra course. The assumption is that the depth of the assessed algebra skill level determines whether the student is prepared to pass any college-level mathematics course that builds upon the level of proficiency determined by the test. Students are deemed proficient in algebra after demonstrating on standardized placement tests that they are capable of completing a series of basic algebra problems such as reducing simple or rational expressions; solving linear, rational and quadratic equations; graphing equations; and factoring polynomials. To assess for this level of algebraic proficiency, colleges often use a single score on a placement test that they either develop on their own or adopt from commercial test designers such as the ACCUPLACER, a popular nationwide test developed by the College Board. Students who do not achieve an appropriate score on the algebra placement test are placed in remedial mathematics courses and are only deemed proficient after passing such courses.

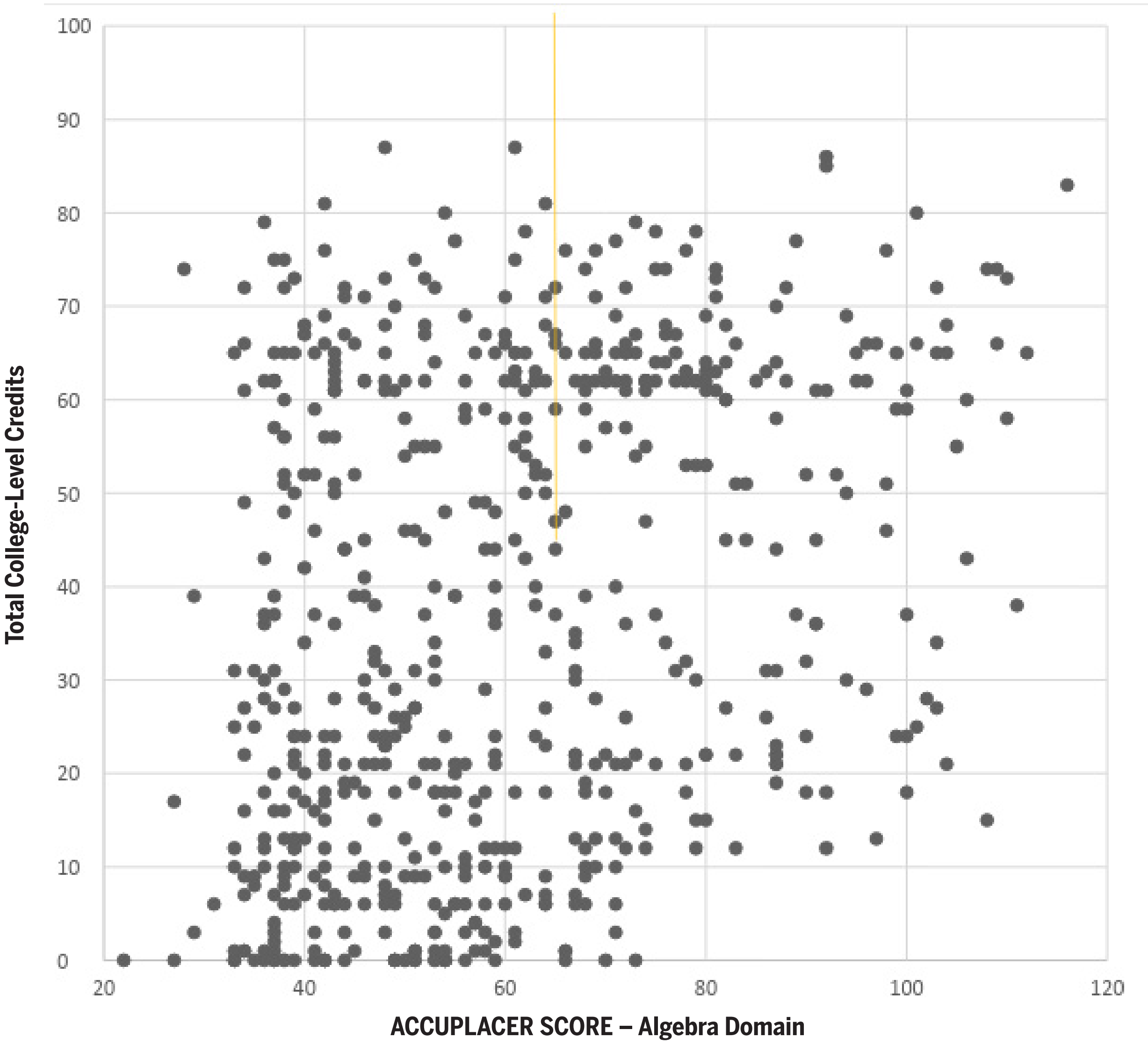
An issue with these commonly used placement practices is the focus on algebra. Proficiency in algebra is equated to proficiency in critical mathematical thinking, thus reinforcing the perception that algebra proficiency is critical for student success in any college-level mathematics course, even those that are not algebra-based. This perception has recently been challenged after numerous research reports have shown that 20 to 50 percent of recent high school graduates and up to 60 percent of students enrolling in community colleges are required to take remediation courses in mathematics (Bailey et al., 2010; Complete College America, 2012). Many students are placed by a single placement test score into sequences of up to three levels of developmental (non-college credit) algebra courses. These students are typically required to pass at least one remedial algebra course before taking a college-level mathematics course, even if that course is not algebra-based and does not utilize skills and knowledge required in the remedial course requirements. According to Complete College America (2012), only 22 percent of community college students will complete both their mathematics remediation and first college-level mathematics course in two years. This process leads to delayed degree attainment—or worse, many students leaving college without a certificate or degree.

Placement and Student Success

Evaluating the actual impact that these traditional placement practices in remedial mathematics have had on student success has been a challenging task for researchers. Ideally, randomly assigning students who place in remedial mathematics courses to either remedial or college-level courses would provide the basis for a valid assessment of the impact of remedial placement. After considering the ethical ramifications of this approach, researchers have adopted a regression discontinuity (RD) approach to assess students who fall near a predetermined cutoff score for college-level placement that mimics random assignment without randomly changing a student's placement. States with mandated cutoff scores have allowed researchers to examine student success in college-level mathematics courses by comparing students who place right below and above the cutoff point to determine the effect of remediation. The rationale behind the RD design is that the participants who fall right above and right below the cutoff point are considered identical, so any difference in success can be attributed to the remedial placement (Melguizo, Bos, Ngo, Mills, & Prather, 2016; Shadish, Cook, & Campbell, 2002). Over the past decade, a few statewide studies have been completed in Florida, Texas, and Ohio using this approach. None of these studies reported any long-term positive impact of placement in remedial coursework (Bettinger & Long, 2009; Calcagno & Long, 2008; Martorel & McFarlin, 2011).

Using a similar RD design but focusing only on non-STEM students, a study of select New Jersey community colleges also showed no positive effect of placement in developmental algebra courses on success in college-level mathematics courses or persistence in college (Austin, 2017). Placement in or out of a developmental algebra course had no correlation to the number of credits a non-STEM student earned over a three-year period (see Figure 1). This study also found that students in their first semester in college, all of whom shared similar proficiency in algebra as determined by scores on the ACCUPLACER test, had a 20 percent higher chance of passing a college-level liberal arts mathematics course than a developmental elementary algebra course (Austin & Austin, 2017). Similar results occurred in a City University of New York (CUNY) study: Students had a 16 percent greater chance of passing a college-level statistics course paired with a supplemental workshop than they had of passing a developmental elementary algebra course (Logue, Wantabe-Rose, & Douglas, 2016). This research demonstrates that the placement in an elementary algebra course is unnecessary for many students to succeed in non-STEM pathways.

Figure 1. 3-year college-level credit totals for non-STEM students by their ACCUPLACER score



Proponents of traditional algebra curricula argue that the foundational skills students learn in algebra extend beyond mathematics courses into further areas of study and professional careers. In rebuttal, the National Center on Education and the Economy (NCEE) argues that algebra content does not provide an appropriate foundation for students in some college-level courses, specifically those that are not part of the statistics or calculus sequence (NCEE, 2013). On examining seven community college course listings across seven states, NCEE found that the majority of entry-level mathematics courses in most majors require little or no algebra skills to succeed, and that most of the mathematics needed to be successful in college is learned in middle school (i.e., arithmetic, ratio, proportions, expressions, and simple equations). Other evidence that developmental mathematics programs are not readying underprepared students for the mathematics they need in college-level courses is the number of students who do not persist but leave college with no credentials for better employment. Figure 1 illustrates a cluster of students to the left of the cutoff who earn few or no credits in three years. Finally, placement in developmental mathematics is shown to have a negative impact on long-term earnings for those who do enter the workforce (Hodara & Xu, 2016). Considering the abundance of recent research that highlights the negative effects of taking developmental mathematics credits on college success and future earnings, policymakers should carefully consider the best placement for students in relation to their career aspirations.

Lasting Change to the Current System

In an effort to address issues regarding lack of student success and misaligned content in early developmental mathematics, mathematics pathways (programs that guide students through a careful sequence of courses relevant to their fields) began to be developed in 2009. By Fall 2015, 58 percent of community colleges implemented redesigned mathematical pathways (Blair, Kirkman, & Maxwell, 2018). Over the last decade, organizations such as the Charles A. Dana Center (see the Preface in this monograph), Carnegie Foundation for the Advancement of Teaching, and the Community College Research Center, along with various statewide initiatives, have encouraged the education and mathematics communities to break the cycle of debt-with-no-degree by structuring curricula that focus on relevant and dramatically shortened mathematics pathways to provide students with opportunities to earn college-level credits as soon as possible (Charles A. Dana Center, n.d.; Community College Research Center, 2015; Hoang, Huang, Sulcer, & Suleyman, 2017). These pathways models include a STEM track, which prepares students for calculus through analysis of functions; a quantitative reasoning non-STEM track, which prepares students for career-relevant, mathematical competency through quantitative literacy; and a statistical reasoning non-STEM track, which prepares students for critical data analyses. Each of these degree pathways requires different areas and levels of mathematical preparedness. A valid assessment of students' mathematical capabilities as they relate to the various pathways is essential to ensure students are placed in the pathway where they will have the greatest likelihood of success in college, while also providing them with timely, relevant remediation as needed.

Placement in Pathways

Traditional placement policies assessing only students' knowledge of algebra are no longer considered appropriate for students in redesigned mathematics pathways programs. Placement into differentiated pathways requires multiple placement criteria. The College Board is scheduled to replace the widely used ACCUPLACER exam with the next-generation Accuplacer by January 2019 (College Board, 2017). This new test will expand the assessment of algebra skills to include quantitative reasoning and statistics among other changes. Even with the change to the test, the College Board recommends that placement tests be supplemented with other measures for better student placement. Multiple criteria include high school transcripts, student waivers, non-cognitive assessments, diagnostic tests, robust advising, and diagnostic placement tests. Institutions that have implemented at least one of these recommendations have shown some improvements in student success as a result of a switch to multiple measures placement policies (Bailey, Jaggars, & Jenkins, 2015; Couturier & Cullinane, 2015).

High School Transcripts

Today, the most recommended reform in placement policies is the use of multiple measures for assessing student preparedness, including consideration of high school transcript data. Key information in high school transcripts includes students' overall success in high school (grade point average) and their success in specific mathematics courses (type of last mathematics course taken, grade, and length of time since the course). Consideration of both high school GPA and the grade earned in the most recently completed mathematics class have shown to be more predictive of student success in college-level mathematics courses than traditional placement practices have been, but the logistics of including multiple measures, such as reviewing high school transcripts for all incoming students, can be challenging (Burdman, 2012). Colleges in states with easily accessible P-20 data systems are more readily able to factor high school information into an overall placement algorithm. Other colleges may only have the resources to review high school transcripts when students challenge their initial placement or use these additional measures when students place just above or just below a cutoff score.

No matter the challenges involved, research is clear that high school transcript evaluation processes should be used along with placement tests to evaluate college readiness (Belfield & Crosta, 2012; Scott-Clayton, 2012). One study conducted at a large community college in 2014 found that when high school transcript data were evaluated alone or in addition to placement test scores, placement error rates decreased while the overall college-level success rates increased (Scott-Clayton, Crosta, & Belfield, 2014). Ngo and Kwon (2016) also found that students who were moved out of developmental courses based on high school transcript data performed, over time, just as well as their counterparts who placed in college-level mathematics through a standardized placement test.

It is important to note that in these studies when high school transcripts were reviewed, high school algebra courses were evaluated in the context of placement into algebra-based pathways. Research that examined non-STEM pathways shows that a proficiency in algebra provides no impact on student success in non-algebra-based, general liberal arts college-level mathematics courses (Austin, 2017). This suggests that, dependent upon the student's desired pathway, a holistic evaluation of high school transcripts can provide more relevant information about a student's ability to perform in a college-level class than exclusive attention to past algebra course success.

Diagnostic Placement Tests

For institutions with limited means and resources to effectively examine individual student high school transcripts, detailed diagnostic placement tests may provide an economical method of assessing student readiness for college-level mathematics courses. Unlike computer-adaptive placement tests, diagnostic tests can provide a breakdown of content-specific skills assessment to better place students in appropriate mathematics pathways. Traditional computer-adaptive placement test results provide a single cutoff score associated with the broad topic of algebra to determine mathematics placement. While the new, next-generation ACCUPLACER does add quantitative reasoning and statistical content to their basic algebra assessment, the single cutoff score may not help educators determine if a student's score is reflective of their quantitative reasoning, statistics, or algebra knowledge. More detailed diagnostic placement tests may provide a better means for assessing students' non-algebraic skills by providing a detailed breakdown of the specific skills in which students are not proficient. In pathways programs where different knowledge may be needed for different paths, the single cutoff score on a computer adaptive placement test will not provide enough information to determine whether students can be successful in the course that relates to their path. Diagnostic placement tests, in contrast, can identify specific mathematical skill levels that can help determine whether students' current mathematical knowledge is sufficient for the specific college-level mathematics course needed for their career path.

Ngo and Melguizo (2016) found that colleges that switched from an in-state diagnostic mathematics test to a standardized computer adaptive test experienced greater placement errors with the computer adaptive test than with the diagnostic test, leading to the researchers' conclusions that diagnostic testing is more accurate at identifying specific mathematics deficiencies. Diagnostic tests can be used to determine if students need remediation in specific pathways. For example, students strong in quantitative reasoning but weak in algebraic reasoning could be placed directly into the college-level statistics course. If the same students were sorted with classic placement strategies, they would be required to take a developmental algebra course prior to taking statistics and risk a greater chance of never completing the degree.

Student Waivers

One of the most controversial of all placement policy changes is the use of student waivers. These waivers allow students to enroll directly in college-level courses with varying degrees of support, regardless of their placement test results. Passed in Fall 2014, Florida Senate Bill 1720 permits all students with a Florida high school diploma who enroll in the Florida College System to either skip the placement test or ignore their placement test results. In the first semester after implementation, enrollment in initial college-level mathematics courses increased by 10.6 percent. While the pass rates for these courses declined 6.9 percent, the overall completion rate increased by 4 percent, meaning more students were getting into and completing college-level mathematics once they could choose to bypass the remedial requirements (Hu, Park, Woods, Tandberg, Richard, & Hankerson, 2016).

Similarly, a small rural college in New Jersey saw graduation rates increase from 25 percent in 2014 to 39 percent in 2016, after it allowed students the choice of how to remediate (i.e., enroll in the full traditional course, participate in a quick review, or skip remediation entirely). To help them make the choice, students were provided extensive academic advising support along with informative statistical reports that detailed the likelihood of success if they chose the traditional remedial path (Austin & Austin, 2017).

Conclusions

Mathematics course placement criteria should be based on a holistic evaluation of student ability to succeed in the appropriate mathematics pathway that is relevant to their career path. Any remediation that is deemed necessary needs to be directly related to the content from the actual college-level courses the students will enter for their degree. Colleges implementing pathways cannot rely on a single, simple test score to determine student placement. Multiple criteria, such as standardized tests, diagnostic tests, and high school transcript data, should be reviewed by trained academic advisors who have honest conversations with students about their current mathematical abilities and future educational goals. Ultimately, students should be allowed to make the final advised, informed choice, as their determination may truly be the best predictor of success.

Given the choice and with appropriate consumer information, more students have elected to enter college-level classes directly with a greater chance of completing the college-level course and graduating than students who enrolled in developmental courses (Austin & Austin, 2017; Hu et al., 2016). To determine the best placement for success, students need to meet with advisors to review their degree goals and placement decision options, considering carefully how the options relate to available academic pathways. With so many different means currently available to evaluate student placement in mathematics courses, the academic advising component appears more vital than ever with regard to all student placement decisions. The time is now for collegewide placement policies to be implemented that do not rely solely on assessment of skills in algebraic manipulation, but rather include assessment of mathematical and quantitative reasoning abilities that align with students' desired fields of study. The multiple-measures practices described in this chapter have a better chance of aiming students toward success in relevant mathematics courses and college completion.

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Chapter 13

Advising and Mathematics Pathways

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Abstract

Postsecondary mathematics curricula are being redesigned to create mathematics pathways that are appropriate for students' career goals. Academic advising is a fundamental component to the success of students and to the effective implementation of mathematics pathways. The focus of this chapter is to describe the role of academic advising in assuring student success, structures of effective academic advising, and the need for advisors' perspectives and understanding in supporting students' course and career choices. The importance of advising in the design and implementation of mathematics pathways, including suggestions for advising STEM majors, will be discussed. The chapter concludes with best practices in advising for faculty, institutions, and policy leaders when implementing mathematics pathways.

Introduction

The movement to design and implement mathematics pathways that offer postsecondary students the opportunity to develop the necessary mathematical and quantitative reasoning skills for their careers has gained both legitimacy and national support in the last decade. As the implementation of these pathways moves toward normative practice, academic advisors are working to effectively advise students to support their academic preparedness, academic abilities, and career aspirations.

This chapter will discuss the importance of advising students—including underrepresented, low-income, and first-generation students—and advisors' impact on student learning, persistence, retention, and degree completion. This chapter discusses how mathematics pathways are changing the landscape of advising and what that means for training and participation of advisors to support students effectively in choosing the most suitable mathematics pathways. The chapter will conclude with recommendations for advisors, faculty, departments, institutions, and policy leaders in advising students from matriculation to degree completion.

Academic Advisement and Its Role in Student Success

Academic advising is an active and engaged partnership with students, impacting students' retention, persistence, and degree completion (Metzner, 1989). Swecker, Fifolt and Searby (2013) state that "good advising might be the single most underestimated characteristic of a successful college experience" (p. 47). They found in their study "that for every meeting with an academic advisor, the odds that a student will be retained increase by 13%" (p. 46).

When students begin college, it is vital that they begin working with their academic advisor(s) immediately. It is paramount that advisors monitor and work with students to ensure that students are on the correct academic trajectory to completing course requirements, completing credit hours each semester, and being active in progress to their degree. Advisors can hold the student accountable for enrolling in and completing their courses. Mandatory advising at various points in the semester or for students reaching certain academic milestones, such as moving from freshman to sophomore, entering the college of their major, or graduation check, is used to keep students on track to degree completion.

Generally, students who have consistent, timely, and meaningful contact with their academic advisor tend to be more self-regulated (Drake, 2011; Kuhn, 2008; Pascarella & Terenzini, 2005). They also have a better awareness of how their academic choices and preparedness affect their future career aspirations. In order for students to be held accountable for their educational journey and success, they should be required to participate in academic advising with specific outcomes for their meetings.

Advances in Advising Practices

Over the decades, academic advising has shifted from being prescriptive—simply giving students the information they need without a discourse with the students on their academic goals—to "advising as a form of teaching" (Lowenstein, 2005). Advising as teaching is a process that allows the advisor to have clear learning outcomes and expectations for students. Additionally, advising as teaching provides a process for advisors to scaffold information to help students think critically about their educational choices. This approach enables advisors to give students strategic and timely information, so they can conduct research and find additional answers to their questions. This form of advising presents students with valuable skills, such as problem solving and critical thinking, particularly useful in mathematics and STEM curricula.

It is critical for advisors to be proactive in advising students, using advising theory or practice such as intrusive or appreciative advising. "Intrusive advising," as defined by Earl (1987), addresses the difficulties that students encounter and makes the appropriate action-oriented intervention. This action can motivate students to continue in courses and their program. With intrusive advising, advisors ask students probing questions to find out how they are performing in their courses, if they are using support services or taking advantage of research/internship opportunities, and if their selected major still fits their long-term goals and career aspirations. "Appreciative advising" calls on advisors to build a positive rapport with students, which helps advisors learn more about the students' strengths, skills, and abilities. It provides a space for students to design their academic and career aspirations and allows them to pursue their academic plans and understand what to expect.

Advising for First-Generation and Underrepresented Minority Students

The number of first-generation and underrepresented minority students attending college is increasing (Engle & Tinto, 2008). These students often need more advice than other students. First-generation students are usually defined as students who come from families in which neither parent has attained a degree beyond high school. First-generation students often "come from low-income and minority backgrounds and face a number of challenges that make it more difficult for them, not only to get into, but through college" (Engle, Bermero, & Obrien, 2008, p. 13). They tend not to have support systems in place to help them through the academic maze. When compared to other students, first-generation students may face different hardships that affect their persistence, such as parents or friends who cannot assist them with the college admission process.

When advising first-generation and underrepresented minority students, it is imperative to take into consideration the "whole" student. One of the most common approaches for advising first-generation students is using "holistic advising" because it focuses on the whole student (Swecker, Fifolt, & Searby, 2013). Holistic advising is defined as advising the student by taking into account their social perspective, financial status, experiences they bring with them to college, noncognitive factors, and academic preparedness. When advising first-generation and underrepresented minority students, consideration of the students' family responsibilities, academic preparedness, and social and financial barriers must be factored into any academic decision.

First-generation and underrepresented minority students need to feel and know they belong. Having an advising model that assigns advisors to students is essential to building a rapport with students. The student–advisor relationship should lead to engaging discourse about issues, challenges, and successes that the student has experienced. Providing mentorings in addition to advising helps students interact with people like them who have succeeded and experienced some of the same barriers but were able to overcome those barriers and be successful.

All first-generation students and especially those who are interested in a STEM major should be engaged in the academic process on the first day of college. Their academic development and persistence should be monitored very closely to ensure that they are on track with their academic goals. Students should not be left to self-advise or be advised by others who do not understand the curriculum, their goals, or their academic preparedness. In particular, when advising first-generation and underrepresented minority students for STEM, it is imperative to make sure that students are linked to mentoring and coaching as soon as possible. Having a structured academic advising process assists with students' retention and persistence in STEM majors (Drake, 2011; Kuhn, 2008; Pascarella & Terenzini, 2005). Self-regulation and intentional and meaningful advisor contact with STEM students are necessary for persistence, for students to stay focused on their major, and for successful degree completion.

Mathematics Pathways and the Impact on Advising

Research has shown that traditional algebra-intensive college mathematics course content does not align with the academic goals or career aspirations of many students (Getz & Ortiz, 2016). Some students believe that they will never use the mathematics content that is taught. The scaled use of mathematics pathways shows that states (specifically, Texas, Oklahoma, Michigan, Washington, and Arkansas) and institutions are beginning to understand the importance of providing relevant concrete mathematics pathways that prepare students for their career aspirations. In 2015, it was reported that 58 percent of public two-year colleges implemented some form of mathematics pathways (Blair et al., 2018, Table TYE.11, p.176). Mathematics pathways are diminishing the stigma of placement in foundational courses that can negatively contribute to students' self-efficacy and contribute to the disenchantment with mathematics courses leading to withdrawal from or failure in the courses (Bahr, 2008).

Mathematics pathways are "developmental and college-level course sequences that align to a student's academic and career goals, and that accelerate student completion of a gateway college-level mathematics course" (Getz & Ortiz, 2016, p. 1). While well-designed mathematics pathways support the success of all students, they are known to provide underprepared and underrepresented students with increased confidence and motivation, thereby also increasing students' self-efficacy in their abilities to complete their mathematics course(s).

Advisors must be at the table when changes are being discussed and implemented to mathematics curriculum and institutional policies. Advisors provide a lens that faculty may not have, such as seeing how making a minor change in mathematics can adversely affect the student's program. In order for mathematics pathways to be truly successful, institutional policies on course placement and course withdrawal should be reviewed with advisors' input. The review will allow advisors to be more successful at holding students accountable when students consider withdrawing from a course. Institutions should ensure that there is adequate support for students from the first day they matriculate on campus to degree completion. Ultimately, it is advisors who are the first contact for students. Well-informed advisors can help students select the appropriate mathematics pathway based on their interests and career aspiration.

Mathematics pathways may ultimately lessen the need for advisors to have the "hard conversation" with students about lack of success in required mathematics courses. In the past, advisors discussed why students had not completed their mathematics requirement, sometimes despite repeated attempts to complete the required mathematics courses. Such discussions can be devastating for students and can lead to students changing majors. Students may become disengaged academically and lose motivation because their major may be perceived to be out of their reach because of a mathematics course. With a predetermined mathematics pathways curriculum, students can take mathematics courses that are appropriate to their major and can lead to a higher rate of success in completing their mathematics requirement. The resulting success in mathematics enables the advising conversation to shift to other dimensions of students' academic paths, such as getting involved in activities (i.e., internship or shadowing opportunities) that support and strengthen their ultimate career goals.

Academic advising workshops in states that have implemented mathematics pathways have shown that advising is critical to the successful implementation of mathematics pathways. However, there is still work that is needed to ensure that advising is part of the discussions and the implementation process from beginning to end. Advising is a necessary component to providing guidance to students on which pathway is best for their academic and career aspirations. Advisors need clarity on the purpose of pathways and how faculty members would like for mathematics pathways to be explained to students. Faculty members and advisors need to develop a relationship for sharing information and working together as partners to better support students.

Conclusion and Recommendations

As mathematics pathways programs grow and evolve in shaping the landscape of mathematics requirements, there needs to be a direct connection to academic advisement. Advisors are critical in the process of helping students to understand their curriculum. Advisors provide insight into questions that students are asking about their mathematics requirements. Advisors are on the front line. They see how changes in mathematics requirements can have a positive or negative impact on students' choice of major program and degree completion. Therefore, advising is one of the critical components to ensure the success of implementation, placement, and assessment of mathematics pathways. Faculty, departments, institutions, and policy leaders should include the following in planning and providing appropriate supports for all students and implementing mathematics pathways:

- Academic advising should begin on the first day of college.
- Advisors should be knowledgeable about different advising models, the needs of all students, and specific needs of first-generation and underrepresented minority students.
- Advisors should be involved in the design and implementation of mathematics pathways, in order to be better equipped to explain the relevance of mathematics courses to students and how particular mathematics pathways fit with particular majors and students' career aspirations.
- Advisors should receive information on the "why" of mathematics pathways so that they are better equipped to explain the benefit of mathematics pathways to students. This knowledge will help advisors to understand the significance of students taking their mathematics course within the first semesters (first year) of their academic journey.
- Academic advising should provide a structured approach for students to be successful in their mathematics courses.
- Advisors and mathematics pathways faculty should work together with a goal of retaining more students in STEM programs and helping students graduate in a timely manner. Faculty members who have the primary advisor role should be trained on advising processes and theories to be able to better assist students holistically.

- Supporting mathematics pathways is a campus-wide endeavor. Institutional policies (such as course placement and course withdrawal) should be aligned with mathematics programs, and appropriate student supports should be implemented.
- When implementing mathematics pathways, there needs to be active involvement and extensive communication amongst internal and external stakeholders. Alignment of policies and programs across sectors—secondary schools, two-year institutions, four-year institutions, and legislatures—is essential to successful implementation.

Academic advising should not be viewed as an afterthought; instead, it should be viewed as a partnership that effectively assists with facilitating mathematics pathways for and communicating them to students. Those partnerships can lead to greater success in college completion as students make better choices about mathematics courses and programs aligned to their academic and career goals.

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Section 4

Equity and Culturally Reinforced

Chapter 14

Mathematics Pathways and Equity:
Considering Progress from Multiple Perspectives

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Abstract
If progress is a matter of perspective, then what perspectives should practitioners and policymakers consider when viewing mathematics pathways through an equity lens? To broaden and deepen the beneficial impact of the mathematics pathways movement, practitioners and policymakers should understand and address equity and student success implications from multiple perspectives held by communities critical to enacting and sustaining change and continuous improvement. This chapter describes four perspectives on equity and student success and concludes with recommendations for successfully obtaining and maintaining "permission" to support broad scale and continuous improvement of mathematics pathways implementation.

Introduction

High-quality mathematics pathways support success for all students, especially underserved populations, by combining strategies for moving students more quickly into credit-bearing gateway mathematics courses that are aligned with programs of study, with strategies for continuously improving teaching and learning (Burdman, Booth, Thorn, Bahr, McNaughtan, & Jackson, 2018; Rutschow, Diamond, & Serna-Wallender, 2017). Effective approaches to mathematics pathways implementation at the lower division postsecondary level are led by faculty members through a process that the Dana Center Mathematics Pathways (DCMP) describes as an educator-driven, administrator-supported, and policy-enabled approach to systemic and sustainable change (DCMP, 2018). "Cycles of mutual permission-giving" are key to successfully enacting this change at scale by engaging stakeholders across multiple levels of the education ecosystem (Cullinane, 2013). In other words, communities of educators, administrators, and policy actors working together must support and be engaged in enacting mathematics pathways at scale to implement the kind of meaningful and long-lasting change that benefits all students, especially underserved communities.

However, there are various perspectives on the goals and priorities related to strategies for advancing student success and equity (Lubienski & Gutiérrez, 2008). Furthermore, approaches to student success often include a mix of strategies, not all of which are explicitly equity focused. This chapter first describes equity and student success from the perspective of multiple communities, and then provides recommendations based on these perspectives for research, policy, and practice related to the mathematics pathways movement.

Community Perspectives on Equity and Student Success

There is broad consensus that equity and equality are substantively different concepts. This difference involves fairness, as opposed to sameness, and the acknowledgment of disparities when considering strategies for supporting all students' success and for pursuing social justice (Council of Chief State School Officers [CCSSO], 2018; Gutiérrez, 2012).

Consensus-derived artifacts about equity, diversity, and student success such as position statements, mission and vision statements, strategic plans, and priority initiatives offer insights into the ways in which the communities from which they derive externally communicate their collective perspectives on these issues. The authors studied several artifacts developed by communities of mathematics educators and professionals, administrators, and policy actors—communities whose perspectives are especially relevant to analyses of equity, student success, and mathematics education. Of particular interest were answers to the following questions: How do these communities publicly describe the people, goals, barriers, and solutions in addressing the issues of equity and student success? In other words, they hope to achieve equity and student success for whom, for what purpose, and how?

Not all artifacts reviewed from these communities convey a perspective on equity. Many solely describe commitments to equality, especially of access and outcomes, or solely of diversity. Almost all equity-focused artifacts contain common elements and keywords, including references to all students, fairness, excellence or quality, disparities or gaps, and meaningful or relevant content and learning experiences. In almost all artifacts, words such as "excellent" or "high-quality" describe the type of learning experiences and resources for which communities advocate (American Association of State Colleges and Universities, 2018; National Association of Mathematicians, 2018). In many of these materials, communities state that the focus of their efforts is on all students and sometimes pair that statement with an emphasis on the types of student groups that they seek to serve, using phrases such as "especially for…" (American Mathematical Association of Two-Year Colleges, 2005). Other artifacts were singularly focused on specific student groups (American Indian Higher Education Consortium [AIHEC], 2012; Association for Women in Mathematics, 2012; Benjamin Banneker Association, Inc. [BBA], 2017; Hispanic Association of Colleges & Universities, 2018). When describing the barriers or problems communities seek to address, most artifacts contain words such as "disparities," which include references to resources, outcomes, and representation (National Council of Supervisors of Mathematics [NCSM] & TODOS: Mathematics for ALL [TODOS], 2016). Several artifacts emphasize the importance of student access to "relevant" or "meaningful" content and learning experiences (Association of Mathematics Teacher Educators, 2015; CCSSO, 2018).

These artifacts also imply various framings of equity and student success that can be conceptualized as narratives, or perspectives on success for whom, for what purpose, and how. Four perspectives and their associated narratives are presented here in simplified form for the purpose of clarity and discussion: *access*, *outcomes*, *diversity and inclusion*, and *social justice*. Each narrative can be viewed with either an equity or equality lens.

Access

The access-focused artifacts that were reviewed by the authors emphasize all students, but when they focus particular groups, they include low-income students, students of color, English learners, and students with disabilities (CCSSO, 2017). Access goals reference closing opportunity gaps; ensuring equal or equitable (depending on the lens employed) access to quality education, resources, and support; and ensuring that personal and social identifiers are not obstacles to accessing educational opportunities nor predictors of access to resources (CCSSO, 2017; National Conference of State Legislatures, 2018; National Council of Teachers of Mathematics [NCTM], 2014). Barriers to achieving these goals include disparities in opportunities or differential access to high-quality teachers, curriculum and instructional opportunities, and too high expectations for mathematics achievement (NCTM, 2012). A primary solution to address these barriers is to provide all students with the unique supports they need to succeed, including effective instruction and leadership, challenging content, and differentiated funding and supports (Atchison, Diffey, Rafa, & Sarubbi, 2017).

Based on these artifacts, an access narrative might sound like this: *All students, especially underserved student groups or those in underresourced learning environments, deserve access to high-quality inputs and learning opportunities. However, disparities in access and opportunity continue to persist, preventing student success. Prominent solutions include providing equal or differentiated funding and supports that include effective instruction and leadership, challenging content, and differentiated or unique supports necessary to succeed.*

According to Gutiérrez (2012), access refers to "tangible resources," including teachers and environments, and is reflective of an "opportunity to learn" equity mindset. This framing of access is in keeping with the perspectives described above. Gutiérrez also cautions that "a focus on access is a necessary but insufficient approach to equity, in part because equal access assumes sameness" (p. 19). Notably, as described above, many contemporary artifacts emphasize that access is about providing targeted supports based on individual need. The artifacts also align with Flores' (2007) research advocating for a reframing of "achievement gaps" in terms of "opportunity gaps" to focus attention on lack of access, rather than "deficit models" that use factors such as culture, poverty, and parental education to explain low performance relative to widely adopted benchmarks.

Outcomes

The outcomes-focused artifacts that were reviewed reference all students, but also emphasize underserved populations, underrepresented students, low-income students, and students of color (American Association of Community Colleges & Association of Community College Trustees, 2016; American Council on Education, 2017; Bennett, 2017; State Higher Education Executive Officers Association [SHEEO], 2017). Outcomes goals focus on educational achievement, including completion of college-level courses, college completion, and post-collegiate outcomes (Bennett, 2017; Kaikkonen, 2017). Barriers emphasize achievement gaps or disparities in educational outcomes and inequities in college readiness (Association of American Colleges & Universities [AAC&U], 2015; SHEEO, 2017). Solutions include programs for nontraditional adult students and targeted, evidence-based intervention strategies, including redesigned mathematics pathways, predictive analytics, and scaling high-impact practices (National Association of System Heads, 2018; SHEEO, 2017).

Based on these artifacts, an outcomes narrative might sound like this: *All students, especially "underprepared" and historically underrepresented and underserved student groups, should be supported to meet or surpass academic achievement and attainment objectives, including college readiness and completion. However, achievement and attainment gaps persist and prevent the field from realizing success for all students. Prominent solutions include targeted, evidence-based programs and interventions.*

Researchers and other influencers have written extensively about themes related to outcomes or achievement in equity and student success, including the strengths and weaknesses of these narratives. The outcomes perspective is often characterized by its data-driven focus. For example, Schmitz (2015) describes collective impact efforts as focusing on the "technical aspect" of equity, or the use of data to "disaggregate results and work to achieve better outcomes for those who are farther behind." The Center for Urban Education (2018) identifies four kinds of educational outcomes related to equity: completion, retention, excellence, and access. The use of these four terms in this way is different but related to the use of the terms in community-developed artifacts. Gutiérrez (2012) describes perspectives on student outcomes as a dimension of equity that she refers to as "achievement," which is measured by "tangible results." Both Gutiérrez (2012) and Leyva (2017) note that outcomes perspectives often do not overlap with perspectives related to students' identities. Lubienski and Gutiérrez (2008) discuss the differences between achievement and advancement perspectives, and the tradeoffs involved in adopting either perspective.

Diversity and Inclusion

The reviewed artifacts that focus on diversity and inclusion center on historically underrepresented student groups or minorities, especially in higher education and in STEM disciplines or the mathematical sciences, and underscore the benefits for all students (American Association of Universities [AAU], 2015; Association of Public & Land-Grant Universities [APLU], 2010; Mathematical Association of America [MAA], 2018). Notably, some artifacts that focus specifically on inclusion use the term marginalized groups, including “people of color, women, people living in poverty, people with disabilities (hidden or otherwise), individuals who identify as LGBTQ+, and individuals who identify as part of a religious minority” (Special Interest Group of the Mathematical Association of America on Research in Undergraduate Mathematics Education [SIGMAA on RUME], 2018). Diversity and inclusion goals include enhancing the diversity of faculty, staff, and students; increasing recruitment, matriculation, and retention; and “making excellence inclusive,” or attending to both demographic diversity and the climates and cultures that support student success (AAC&U, 2013; APLU, 2018; Society for Industrial and Applied Mathematics, 2017).

Barriers to achieving these goals include a lack of representation in senior roles, an unwelcoming atmosphere in postsecondary STEM classes and seminars, bias or low expectations, lack of awareness by students about STEM, and views that excellent education should be exclusive or “reserved for the few” (AAC&U, 2013; Association of Symbolic Logic [ASL], 2018; Society of Actuaries, 2018). Solutions include outreach events (e.g., conferences and workshops); engagement and mentorship programs; awareness-building among students in high schools, colleges, and universities; advising or encouraging students to advance or make continuous progress throughout their academic and professional careers; using race as one of many factors in making individual admissions and hiring decisions; and fostering environments that honor, respect, and embrace diversity (AAU, 2015; American Mathematical Society, 2018; American Statistical Association, 2016; SIGMAA on RUME, 2018; SOA, 2018). In addition, where the potential of students can be attained at the highest level possible, an initiative would focus on recruiting and inviting scholars to fully participate in the community and in leadership, attend to gender imbalance, and develop opportunities for involvement (ASL, 2018; Denton, 2017; MAA, 2018).

Based on these artifacts, a diversity and inclusion narrative might sound like this: *All students, especially low-performing and historically underrepresented and marginalized student groups, should be proportionally represented and authentically engaged in academic and professional roles and environments, such that students advance in academic and professional pipelines, especially those of high value. However, disparities in representation and inclusion persist. Prominent solutions include the development of mentorship programs, and the fostering of welcoming learning environments and academic and professional cultures.*

Of Gutiérrez’s (2012) dimensions of equity, the goals of the diversity perspective most closely align with “achievement,” involving participation in the math pipeline, especially for underrepresented student groups. However, the focus on authentic engagement in the inclusion perspective aligns more closely with Gutiérrez’s “identity” dimension of equity, which is a response to the danger that some students experience to “play down their personal, cultural, or linguistic capacities in order to participate in the classroom or the math pipeline.” Aguirre, Mayfield-Ingram, and Martin (2013) describe attention to issues of identity as key to teachers’ development of “richer perspectives and practices” (p. 5-6) on issues of equity. Notably, the Center for Urban Education (2018) notes the potential weaknesses of perspectives focused on diversity:

> . . . a diversity lens focuses only on bringing more students into an unequal pathway. In contrast, equity redirects resources to the pathways with greatest need to fix barriers and intentionally provide support. (p. 1)

Social Justice

The reviewed artifacts that focused on social justice reference all students or "American young people," with an emphasis on groups that have been historically marginalized and underserved in mathematics education and society. A few artifacts centered exclusively on specific student groups, including African American students and students in Tribal Colleges (AIHEC, 2012; BBA, 2017; NCSM & TODOS, 2016). Goals described in social justice artifacts include both those that advocate for a systemic approach—"a just, equitable, and sustainable system of mathematics education for all children" (NCSM & TODOS, 2016, p. 1)—as well as those focused on curriculum—"to facilitate authentic, meaningful relationships between African-American students . . . and those who are responsible for their education" (BBA, 2017, p. 1). The barriers to achieving these goals include deficit views of mathematics ability; disparities in learning opportunities and outcomes in mathematics education based on race, class, culture, language, and gender; and mathematics as gatekeeper, or the use of mathematics as a gatekeeping tool to sort and rank students by race, class, and gender, beginning in elementary school. Solutions offered include acknowledgment that the current mathematics education system is unjust and grounded in a legacy of institutional discrimination based on race, ethnicity, class, and gender; and the creation and sustainment of institutional structures, policies, and practices as part of a systemic plan that leads to just and equitable learning opportunities, experiences, and outcomes for students.

Based on these artifacts, a social justice narrative might sound like this: *All students, especially student groups that have been historically marginalized and underserved in mathematics education and society, deserve to learn in a just, equitable, and sustainable system of mathematics education in which students succeed and critically apply knowledge and skills to learning about and addressing social issues. However, deficit views, disparities in mathematics learning opportunities and outcomes, and the use of mathematics as a gatekeeping tool persist and prevent the achievement of this goal. To overcome these barriers, advocates recommend acknowledging the injustices of the current system and taking action at multiple levels of the system to create and sustain institutional structures, policies, and practices that lead to just and equitable learning opportunities, experiences, and outcomes for all students.*

For those social justice advocates focused on curriculum, this perspective aligns closely with Gutiérrez's (2012) description of the Identity dimension of equity in which students have opportunities to see themselves in the curriculum and have a view of a broader world. However, to several researchers and advocates, this perspective is primarily about power or empowerment. Gutiérrez describes the "power" dimension of equity as taking up issues of social transformation at many levels, including using mathematics as an analytical tool to critique society. In 2016, the National Council of Teachers of Mathematics (NCTM) endorsed a joint position statement on social justice with the mathematics professional associations National Council of Supervisors of Mathematics and TODOS: Mathematics for ALL. One of the ways in which NCTM is acting upon this endorsement is by embracing the concept of empowerment in its guidance for teachers and including topics of student identity, agency, and teaching mathematics for social justice (Larson, 2016).

Discussion and Recommendations

This chapter provides a framework for examining commonly raised questions about equity and mathematics pathways while viewing mathematics pathways through an equity lens. The first part of the chapter adjusts readers' vision to align with equity lenses, or various perspectives on the definitions of equity in mathematics education and related goals. Based on equity implications of these perspectives, the chapter concludes with recommendations for stakeholders at multiple system levels who are engaged with or considering engagement with the mathematics pathways approach to student success.

The artifacts described in this chapter represent the product of negotiated consensus of the mathematics, administrator, and policy communities, more so than research and commentary by any single thought leader or other representative. As described earlier, effective implementation of mathematics pathways at scale depends on these communities negotiating and forming a collective vision and plan for student success.

Multiple approaches are represented in each community's artifacts. Indeed, multiple approaches are often used by the same organization—frequently in the same artifact. Given the complexities of student success, it is reasonable and likely preferable that organizations adopt multiple approaches to form a multidimensional student success strategy.

The recommendations in this section are based on the findings from a review of these artifacts.

1. Identify dimensions of equity and aligned metrics.

When stakeholders representing multiple communities come together, it is critical that their discussions are informed by data and evidence. However, currently available reports tend to focus on access and attainment. Although these data are important, they do not provide enough information to fully evaluate progress for those whose equity and student success goals are aligned with diversity and inclusion or social justice perspectives. At the same time, the four perspectives described in this chapter are not distinct enough to support the identification of aligned metrics. Researchers should identify valid and reliable metrics aligned with multiple distinct dimensions of equity expressed by the mathematics, administrator, and policy communities. For example, these dimensions might include access, attainment, advancement, authentic engagement, and empowerment. Once developed, practitioners and policymakers should utilize metrics that are aligned with multiple dimensions of equity when evaluating the progress of mathematics pathways approaches.

2. Consider equity implications for planning and action from multiple perspectives.

Practitioners should use multiple perspectives to consider the equity implications of mathematics pathways approaches when planning for implementation and continuous improvement. Policymakers should consider and address the potential tradeoffs and unintended consequences of narrowly attending to particular dimensions of equity, outside of or disconnected from a comprehensive strategy for equity and student success.

3. Support stakeholders in considering multiple perspectives.

Stakeholders should strive to engage in open conversations to address questions about equity and mathematics pathways that reflect various priorities and perspectives. For example, concerns about tracking have frequently come up in discussions with practitioners (Boaler, 2011; Burris, Welner, Wiley, & Murphy, 2008; Stiff, Johnson, & Akos, 2011). These concerns are often rooted in a desire to ensure that students from underserved communities are able to enter into and persist in particular "pipelines" (e.g., STEM) to upward mobility. To engage in this discussion, stakeholders would need data related to access, attainment, and advancement dimensions of equity. With data and guidance to facilitate conversations among those with diverse perspectives, stakeholders at multiple levels of the system would be better equipped to develop effective and long-lasting solutions.

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Chapter 15

Mathematics Pathways and Equity:

Gateway Course Outcomes

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Abstract

Mathematics pathways seek to achieve comprehensive success outcomes for all students, especially underserved populations, by combining structural approaches to move students more quickly into credit-bearing gateway mathematics courses aligned with programs of study and strategies for continuous improvement in teaching and learning. This chapter presents findings from qualitative and quantitative reports of prominent mathematics pathways approaches to provide a picture of where mathematics pathways efforts are progressing toward achieving equity goals. Significant strides have been made throughout the pathways movement to improve the overall success and mathematical achievement of developmental students while shortening the time required in remedial coursework. While mathematics pathways approaches have measurably increased success rates for Black and Latino students in particular, additional work is needed to better understand and address persistent achievement and opportunity gap issues for all underserved and underrepresented student groups. Finally, recommendations for researchers, policymakers, and practitioners are offered for consideration in the field.

Introduction

Many view mathematics pathways approaches to addressing remediation as an essential strategy for advancing student success and equity in education (Hern & Brezina, 2016). Thought leaders of mathematics pathways approaches, including Uri Treisman, executive director of the Charles A. Dana Center, and Myra Snell, co-founder of the California Acceleration Project, have emphasized equity and student success from the beginning of the mathematics pathways movement (Bryk & Treisman, 2010; Maitre, 2014; Meyer, 2013). Equity is also an important motivator for individuals engaged in improving mathematics education and student success (Ellis & Leahy, 2017; Robots & Pencils, 2017).

Indeed, equity has been a central motivator for leading educators', administrators', and policymakers' work on mathematics pathways (Charles A. Dana Center, 2016a, 2016b; Robots & Pencils, 2017). However, little has been written explicitly addressing equity and mathematics pathways. The focus of this chapter is to highlight the gateway course outcomes for students of color and low-income students in three prominent mathematics pathways initiatives: Carnegie Math Pathways, the California Acceleration Project, and the Dana Center Mathematics Pathways.

Mathematics is more important than ever before to students' future roles as scholars, as professionals, and in life due to shifts in the economy, academia, and society (Leahy & Landel, 2017; National Research Council, 2013; Treisman, 2015). However, disparities persist for underserved and underrepresented student groups, including low-income students and students of color, in mathematics success, which also impact their access to and participation in STEM-related careers and professions (Whittaker & Montgomery, 2012). Furthermore, postsecondary mathematics has been identified as one of the most significant barriers to student success and post-college outcomes (Bressoud, 2018). Given this reality, increasing numbers of stakeholders at multiple levels of the education system are addressing mathematics education as a critical component of their student success agendas.

In a growing number of states, systems, regions, and institutions, practitioners and policymakers are responding to this critical need by recommending and implementing mathematics pathways at the lower division level (Charles A. Dana Center, 2016a). These efforts are characterized by their strategies to increase program coherence and alignment, replace extended developmental sequences with accelerated and corequisite learning options, offer and assure broad acceptance of the "right" mathematics for programs of study, and improve and incorporate research-based knowledge into mathematics curriculum design and pedagogy. Mathematics pathways approaches seek to coherently combine strategies designed to address, through mathematics, the key structural, curricular, and pedagogical barriers to success in college, career, and civic roles.

Mathematics Pathways Approaches and Student Success Outcomes

What do we know about mathematics pathways and student success outcomes, relevant to equity or fairness? What evidence exists that can inform considerations of mathematics pathways through an equity lens? Multiple reports have assessed the impact of prominent mathematics pathways approaches on student success; their results are highlighted below.

Carnegie's Quantway™ and Statway™

The Statway and Quantway curricula of the Carnegie Math Pathways have been implemented in 56 institutions in 14 states across the country. Evidence suggests that these pathways have achieved measurable success for all students, including students of color and students of poverty, in half the time relative to traditional developmental education (Carnegie Math Pathways, 2018). A 2013 report on the Carnegie Mathematics Pathways emphasized that "the pathways reach the students whom community colleges need to serve well. A disproportionate number are minority students, from families whose primary language is not English, and the first in their families to pursue a college degree" (Clyburn, 2013, p. 18).

In a comparison of Statway students to students in traditional developmental mathematics sequences at community colleges and four-year institutions across 10 states, 58 percent of Statway students earned a grade of C or above in a college-level mathematics course, while only 22 percent of the comparison group achieved the same (Huang & Yamada, 2017, p. 2).

Students of color in Statway and Quantway tended to outperform their counterparts in traditional mathematics course sequences (Huang & Yamada, 2017; Klipple, 2016). Black Statway students showed a success rate of 43 to 47 percent in the college-level mathematics courses versus their comparison group at five to seven percent. Similarly, success rates for Latinos in Statway courses ranged from 36 to 42 percent compared to Latino students in traditional courses with success rates of seven to eight percent (Klipple, 2016). Additional data showed that Statway has a positive effect across all racial/ethnic and gender groups, with Black females showing the largest gain in mathematics achievement when compared to their baseline performance (Huang & Yamada, 2017).

Results were similar for Quantway. Yamada, Bohannon and Grunow (2016) studied the success of Quantway 1 (the developmental mathematics course preparing students for Quantway 2) during the first six semesters of course implementation at 10 institutions. Researchers found that Quantway students "demonstrated significantly higher odds of success than matched comparison students in fulfilling developmental mathematics course requirements" (Yamada et al., 2016, p. 2). The study found positive effects for Quantway 1 across all gender and racial/ethnic subgroups with male Black and Latino students, demonstrating the largest increase in completion rates (Yamada et al., 2016). Success rates for Black students in developmental mathematics ranged from 46 to 48 percent for Quantway students versus 24 to 28 percent for the comparison group (Klipple, 2016). For Latinos, success rates in Quantway were 66 to 69 percent, compared to 35 percent for the traditionally enrolled Hispanic student (Klipple, 2016).

For all students, evidence indicates that Quantway and Statway also showed a positive effect on degree completion and credential attainment. In a recent study, pathway students (Quantway or Statway) earned Associates of Arts degrees and other credentials at a similar or higher rate than comparison traditional students deemed college-ready (Norman, 2017). Similarly, both Quantway and Statway students from a 2010 and 2011 cohort transferred to four-year institutions at much higher rates than the comparison students who had more time to transfer (Norman, 2017).

California Acceleration Project (CAP)

Founded in 2010, the California Acceleration Project is a mathematics pathways approach implemented in 84 community colleges in California, which multiple studies have found to measurably increase student success in less time than traditional developmental education, including for students of color and low-income students (California Acceleration Project, 2018).

For CAP, implementing redesigned pathways includes just-in-time remediation aligned to programs of study and a placement approach including multiple measures and placement floors (Hern & Brezina, 2016; Henson, Hearn, & Snell, 2017). CAP leaders have spoken out about the social justice imperative of improving developmental and mathematics education:

In the California Acceleration Project (CAP), we help faculty understand that the policies and curricula that higher education has developed to help students who are considered "underprepared" are actually making these students less likely to succeed in college—and further, that students of color are bearing the brunt of the unintended consequences (Hern & Brezina, 2016, p. 1).

Hayward and Willet (2014) analyzed student outcomes from 16 CAP colleges offering redesigned English and mathematics pathways in 2011 and 2012. All 16 institutions showed a significant reduction in time for students to complete developmental courses without any changes being made to the transfer-level course or requirements for entry into the aligned pathways (Hayward & Willet, 2014).

The researchers found that 38 percent of CAP mathematics students completed the transfer-level college mathematics course in the sequence compared to 12 percent of the comparable non-CAP students. CAP students who were placed one or two levels below completed the transfer-level college mathematics course at success rates of 53 and 41 percent, respectively, compared to comparison traditional students' completion rates of 23 and 15 percent. Ultimately, the odds of students in the accelerated mathematics pathway completing transfer-level college mathematics were about 4.5 times greater than the odds for students in the traditional sequence (Hayward & Willet, 2014, p. 29).

At Cuyamaca College in California, all students are now eligible for a college-level, transferable statistics course with co-requisite support, and 62 percent can take transfer-level math courses in business/STEM areas with or without support. All other business/STEM students have only one semester of remediation (intermediate algebra) with or without support (Henson, Huntsman, Hern, & Snell, 2017). The College of the Canyons had similar results with 100 percent eligible for transfer-level mathematics compared to 15 percent of students previously (Henson, Huntsman, Hern, & Snell, 2017).

Evidence indicates that CAP has a positive effect on success and completion among students of color. Black CAP students have the same odds of completing the mathematics pathways as their White counterparts, minimizing or successfully eliminating the achievement gap (Hayward & Willet, 2014). Likewise, at Cuyamaca College and the College of the Canyons, "gaps in access to college-level [transfer-level] mathematics were reduced or eliminated across all racial/ethnic groups. African American students' access increased eightfold, and Hispanic students' access increased fourfold" (Henson et al., p. 2). Black students in the statistics pathway in CAP at the College of the Canyons were three times as likely as their peers in the traditional developmental sequence to complete their credit-level [transferable] mathematics course within two years (Hern & Brezina, 2016).

Despite results demonstrating higher success rates for students of color in CAP completing the transfer-level course than traditionally enrolled counterparts, persistent gaps remained between White students and Hispanic and Black students. A 2015 study of CAP conducted by Hayward and Willet (2015) showed success rates for students completing a transfer-level mathematics course were approximately 44 percent for White CAP students compared to about 41 and 35 percent for students who are Black and Latino, respectively. It should also be noted that, of students placing three or four levels below the transfer-level course (lowest two levels), 32.3 percent of Hispanics completed the transfer-level course and 48.6 percent of Black students. This was higher than White students at 42.9 percent (Hayward & Willet, 2015). While researchers note that evidence at this point may be inconclusive since results differed based on level of placement, results were still promising and suggested that the CAP pathway is well on the way to addressing—although not always eliminating—mathematics achievement gaps (Hayward & Willet, 2014).

Dana Center Mathematics Pathways (DCMP)

The Dana Center Mathematics Pathways (DCMP) model has been implemented in educational systems in over 16 states across the country. The Dana Center makes the case that many more students will successfully learn mathematics in rigorous and relevant courses that are part of well-designed mathematics pathways aligned to programs of study and that allow students to enter into college-level courses within their first year of college enrollment (Charles A. Dana Center, 2016a). This model emphasizes major structural changes that can be implemented quickly and that have a large positive impact on student success. Then, faculty and student support services can focus their attention on continuous improvement efforts through the integration and alignment of student success strategies and evidence-based curriculum and pedagogy. Equity is an integral part of the DCMP (n.d.):

> All students deserve to be served by a system that innovates in both meaningful and sustainable ways. The Dana Center Mathematics Pathways enacts the Charles A. Dana Center's mantra "Equity. Access. Excellence." through the multiple mathematics pathways approach. This approach prepares all students to use mathematical and quantitative reasoning skills in their careers and personal lives, enables timely progress toward completion of a certificate or degree, and develops empowered mathematical learners.

The evidence described below indicates that the Dana Center curriculum has measurably increased student success in Texas institutions, including for students of color and low-income students, in less time than traditional developmental education. In addition, students enrolled in the New Mathways Project statistics pathway were more engaged and achieved higher grades and pass rates when compared to those enrolled in traditional algebra-intensive mathematics courses (Charles A. Dana Center, 2016a, p. 4).

DCMP students reported being "surprised by how relevant mathematics could be to their lives and how they could more critically evaluate everyday quantitative information. . . . Many had started in the NMP classes feeling they could never grasp mathematics, and many left . . . more confident in their ability to approach the quantitative issues that they face in their everyday lives" (Rutschow & Diamond, 2015, p. 53). In addition, DCMP students completed their credit-bearing mathematics classes within one year whereas the comparison traditional student can take as long as three years (Charles A. Dana Center, 2016a).

Schudde and Kiesler (2017) found that DCMP students were more likely to complete their developmental mathematics requirements and enroll in and pass credit-level mathematics courses than students enrolled in the traditional mathematics sequence. When comparing NMP students to those in a two- or three- course traditional developmental math sequence, NMP students were about 10 percentage points more likely than their peers to pass their developmental math course, and seven percentage points more likely to persist into the next semester. Students in the NMP *Foundations for Mathematical Reasoning* course were approximately 28 percentage points more likely to enroll in college-level math in the subsequent semester and 42 percentage points more likely to pass the class. When compared to a traditional, one-term “dev-ed” math course, assignment to the NMP *Foundations* course increased the probability of enrolling in a college-level math course the next semester by about nine percentage points and of passing that course by 25 percentage points (Schudde & Kiesler, 2017).

Co-requisite Models: A Promising Pathways Structure

In addition to the pathways approaches previously discussed, several states have shown promise in improving mathematics success and completion rates with mathematics reform and pathway implementation unique to their state (Denley, 2016; Logue, Watanabe-Rose, & Douglas, 2016). For example, beginning in Fall 2015, Tennessee scaled a co-requisite pathway model across all public universities and community colleges. Full implementation of the co-requisite model across the state showed substantial increases in completion of the credit-level mathematics course with 55 percent successful completion (compared to only 12.3 percent success for the previous traditional model) for students across all ability levels, as determined by ACT scores (Denley, 2016). When the model was revised to include a co-requisite lab instead of a co-requisite course, 75 percent of students in the co-requisite track passed the credit mathematics course, with 67 percent passing in their first semester (Denley, 2016).

Significant gains were shown across all ACT score levels. The achievement gap was essentially eliminated with successful college-level course completion for 73 percent of minority students compared to 75 percent success for all students, with 72 percent of low-income students passing the credit course. The success rate of “minority” students increased by seven times to 47.3 percent (Denley, 2016).

The City University of New York (CUNY) system has also shown gains in a co-requisite model approach with higher success rates for students enrolled in an Elementary Algebra course with a co-requisite support model (about 45 percent) compared to students enrolled only in the Elementary Algebra course at around 39 percent (Logue et al., 2016). Similarly, there were minimal differences in course success rates of approximately 67 percent for students enrolled in an Introductory Statistics course with co-requisite workshops compared to 69 percent for students in the control group. Although the percentage of course success was slightly lower for the co-requisite group, results were still impressive in that the students in the co-requisite group were those identified as needing remediation, and those in the control group who were deemed college-ready.

In addition, the statistics students with additional support passed statistics (a college-level/transferable course) at a much higher rate than the elementary algebra students, even though all students required remediation (Logue et al., 2016). The progress made by the CUNY implementation was encouraging, considering that 66 percent and 68 percent of all students in the system were Pell-eligible or Black/Hispanic, respectively (Logue et al., 2016).

Discussion on Equity and Mathematics Pathways Design

Many early implementations of mathematics pathways focused initially on developmental students because of the gains that can be made in student success through the acceleration of a pathway. Low-income students, students of color, and first-generation students are overrepresented in developmental courses, and gains in student success in these courses help close the achievement gap. The evidence of high failure rates in traditional developmental mathematics sequences created a moral imperative to focus first on this population. Given that students requiring remediation and those less likely to complete credit-level mathematics are often students of color and low-income students, these results suggest that mathematics pathways approaches are promising strategies for increasing success for these student groups (Attewell, Lavin, Domina, & Levey, 2006; Bailey, Jeong, & Cho, 2010; Chen, 2016).

Since first developing their mathematics pathways approach, the Dana Center has expanded the vision of mathematics pathways to encompass entry-level college students because all students need and deserve the opportunity to learn mathematics content that is meaningful to their academic and career goals and learn that content in an environment designed to enhance their development as independent learners and critical thinkers. Furthermore, to imply that pathways only apply to developmental students actually perpetuates inequity by establishing a two-tiered system in which students who place directly into college-level mathematics are funneled into College Algebra or STEM pathways, and developmental students are funneled into alternative pathways. This inevitably leads to a perception that the non-algebraic-intensive pathways are less rigorous and less desirable.

The whole concept of mathematics pathways hinges on establishing a set of rigorous gateway mathematics courses appropriately aligned to programs of study that all carry equal legitimacy. Mathematics pathways advocates emphasize that students should select a pathway based on its content and alignment with their program of study, not on their placement (Charles A. Dana Center, 2014).

The Dana Center is also pushing the field to redesign and re-envision all pathways, including the traditional Algebra pathway (e.g., Intermediate Algebra, College Algebra, Trigonometry, Precalculus) leading to Calculus. There is growing evidence that the traditional pathway to calculus is not effective for students who enter at the level of College Algebra or below (Sonnert & Sadler, 2014). The Mathematical Association of America National Study of College Calculus found that three-quarters of college students who eventually study Calculus took this course in high school (Bressoud, Mesa, & Rasmussen, 2015). The study also notes that most students enrolled in college Calculus had a successful record from high school mathematics, with an average high-school mathematics grade above a B+ across all types of institutions. It is reasonable to conclude then that college calculus courses are designed for those that have previously taken this course and that have previously succeeded in mathematics—putting non-calculus students and less successful mathematics students at a disadvantage.

This demonstrates the need to reevaluate the traditional Algebra pathway to both seek ways to create access for students with less successful high school records, and to redesign mathematics programs in grades 11 and 12 to identify struggling students before they graduate and to accelerate their path toward college readiness. Marilyn Carlson's work on preparing students for calculus is exemplary of the kind of research that has broadened educators' awareness of the need to revise the traditional pathway to calculus in alignment with findings on how students learn and retain mathematical knowledge, specifically in calculus (Carlson, Oehrtman, & Engelke, 2010). This is especially critical if the United States is to expand the number of underrepresented minorities and low-income students entering the STEM fields.

Recommendations

Although significant strides have been made throughout the pathways movement to improve the overall success and mathematical achievement of developmental students while shortening the time required in remedial coursework, additional work is needed to address persistent achievement and opportunity gap issues, as well as strengthen the commitment to advancing structural reforms that do not result in unintended consequences such as tracking.

Furthermore, there is broad consensus that equity and equality are substantively different concepts and that this difference involves fairness, as opposed to sameness, and the acknowledgement of disparities when considering strategies for supporting all students' success and, for some, pursuing social justice (Gutiérrez, 2012). However, there are various perspectives and priorities related to the populations served, as well as a range of goals and strategies for advancing student success and equity (Lubienski & Gutiérrez, 2008).

The authors recommend the following research and actions that would facilitate further gains in closing achievement gaps:

- Researchers should conduct additional research to understand the conditions that led to the closing or narrowing of disparities/achievement gaps through various mathematics pathways approaches.
- There is a need for additional research into the short-term and long- term outcomes for other student groups referenced in equity and student success narratives that reflect various equity perspectives and priorities. These include women in STEM, English learners, first-generation students, adult learners, and all underserved and historically marginalized student groups and academic institutions.
- Given the variety of perspectives on equity amongst stakeholders critical to implementing change in mathematics education, researchers should identify valid and reliable indicators and performance measures aligned with multiple dimensions of equity, including access, attainment, advancement, engagement, and empowerment.
- When evaluating the progress of mathematics pathways approaches, all stakeholders should utilize metrics aligned with multiple dimensions of equity. For their part, it is incumbent upon policymakers to analyze and investigate the potential tradeoffs and unintended consequences of narrowly attending to particular dimensions of equity, disconnected from a comprehensive strategy for equity and student success.
- Practitioners, including educators and administrators, should strive to engage in open conversations to identify and address the many questions about equity and mathematics pathways that reflect various priorities and perspectives on equity and student success.

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