Mathematics Re-Design in American Higher Education: A Literature Review & Introduction to Florida Data to Inform Mathematics Re-Design Workgroups

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Introduction

In 2018, the Florida College System (FCS) launched the Florida Student Success Center in partnership with Jobs for the Future, Helios Education Foundation, and the Florida College System Foundation. The role of the center is to support institutional initiatives that improve college completion rates and promote student success. Mathematics pathways re-design and content alignment are primary initiatives of the Florida Student Success Center to increase student success rates. To achieve this goal, mathematics faculty, administrators and key stakeholders were invited to participate in inter-connected workgroups to align mathematics content and pathways that best prepare students for their intended academic and career goals.

The charge of the Florida Mathematics Re-Design workgroups is to explore complex issues surrounding mathematics pathways to prepare: high school students for transition into postsecondary; Florida College System students for success in gateway courses aligned to their programs; and Florida College System students for transition into four-year universities. The focus of the three workgroups is detailed below:

1. The **High School to Postsecondary Alignment** workgroup will examine how high school curriculum in mathematics aligns with postsecondary expectations, which may include: clarifying what college entrance-requirements are and how they align with high school assessments and courses; examining the longitudinal student data on mathematics sequencing and student success rates; engaging high school and college mathematics faculty in dialogue about postsecondary expectations; and identifying strategies that promote greater alignment of curriculum and content.

2. The **FCS Mathematics Sequences** workgroup will examine multiple pathways for students to enter based on programs of study as well as the re-design of course structures (e.g., delivery, curriculum and pedagogy) to maximize support for students, which may include: identifying course and institutional structures that deter success; encouraging the modernization of mathematics content; reviewing data on student success across algebra and non-algebra pathways; and working with faculty to identify a sequence of courses in the context of a student's intended transfer major/meta-major.

3. The **FCS to University Alignment** workgroup will examine how FCS curriculum in mathematics aligns with university expectations, particularly for students in transfer programs, which may include: clarifying what university requirements are; examining the longitudinal student data on mathematics sequencing and student success rates; engaging FCS and SUS mathematics faculty in dialogue about postsecondary expectations; and identifying strategies that promote greater alignment of curriculum and content.

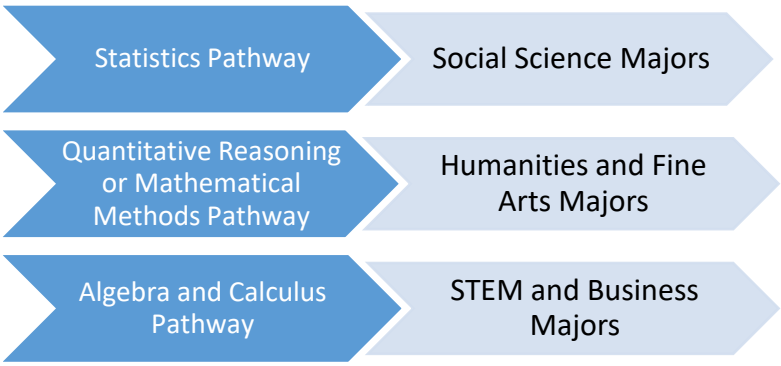
The groups will collaborate to identify current challenges in mathematics pathways and develop policy and practice recommendations to improve student achievement across education systems.
This document is developed as a resource for the mathematics workgroups to provide an introduction to mathematics re-design in American postsecondary education. It includes a high-level review of national mathematics re-design initiatives and select policy and research papers, with additional data and information from Florida. It is not an exhaustive summary of all the literature and research surrounding postsecondary mathematics.

The Challenge

Mathematics can be a Roadblock for Students

Two major factors shape mathematics as a potential barrier for students: long course sequences and mismatch of content. According to the U.S. Department of Education, 70 percent of students in developmental education never enroll in credit-bearing mathematics courses and nearly half of students in credit-bearing mathematics courses fail, creating a longer pathway to degree completion.

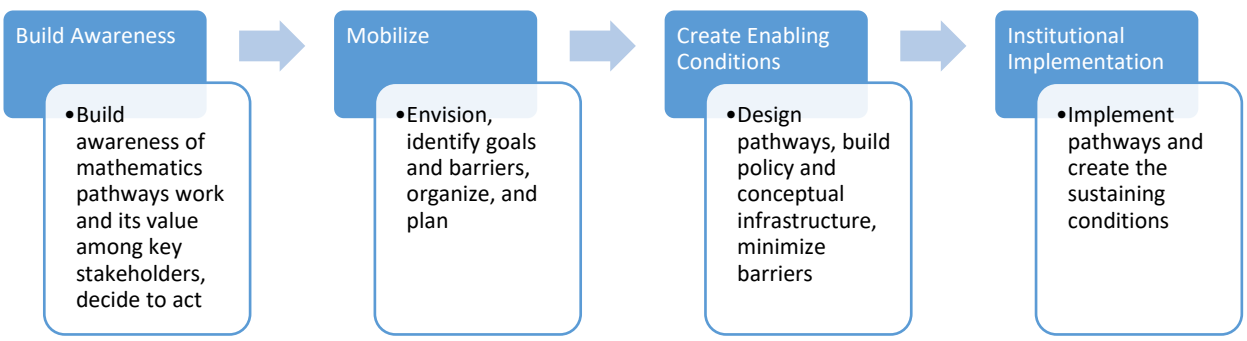
Approach to New Mathematics Pathways



The traditional approach to mathematics coursework divided students into two groups: those whose major required Calculus and those that do not. In this approach, all students participated in the Algebra and Calculus pathway, resulting in a lack of student engagement with mathematics coursework. The new pathways are designed to provide mathematics coursework relevant to students in different majors to increase engagement. In these pathways, only STEM and Business majors who need Calculus are in the Algebra and Calculus pathway. Contextualizing mathematics can remove students' initial fear and increase their understanding, appreciation, and efficacy in math.

Steps to Implementing New Mathematics Pathways

The literature provides a change process that leads to institutional implementation of new mathematics pathways designed to remove the mathematics barriers to degree completion. To provide a more streamlined pathway, high school and postsecondary alignment in mathematics coursework is imperative to increasing student success.



Sources: (AMPSS, 2018; Dana Center, 2016; Summit on Mathematics Pathways, 2017)

Mathematics Re-Design in American Higher Education

Fueled by the national focus on educational attainment to match current and future workforce needs, postsecondary leaders are illuminating barriers to college completion and seeking answers on how to address these challenges. Mathematics education is among the challenges discussed. Recently, Advancing Mathematics Pathways for Student Success (AMPSS), a coalition[1] to coordinate a national drive to address undergraduate mathematics as an academic barrier for students pursuing degrees and credentials that includes a partnership between released a draft report entitled, *National Strategy for Advancing Mathematics Pathways for Student Success*, stating "Gateway and developmental mathematics courses pose the most significant academic barrier to postsecondary attainment for millions of students each year, especially those from underrepresented or nontraditional groups of college students" (AMPSS, 2017, p. 2).

The relationship of mathematics coursework on degree completion has been documented by education researchers and scholars. Sax and Brady (2015), writing on behalf of the Mathematical Association of America's *A Common Vision* project, a joint effort, focused on modernizing undergraduate programs in the mathematical sciences, of the American Mathematical Association of Two-Year Colleges (AMATYC), the American Mathematical Society (AMS), the American Statistical Association (ASA), the Mathematical Association of America (MAA), and the Society for Industrial and Applied Mathematics (SIAM). The authors write, "The high rate of failure in post-secondary mathematics classes… is a major contributor to increased attrition rates, and it lengthens time to degree at all types of post-secondary institutions. Mathematics courses are the most significant barrier to degree completion in both STEM and non-STEM fields" (p. 28).

The Dana Center identifies two structural drivers of the mathematics problem. First, mathematics course sequences are too long and "underestimate the capability of students to learn mathematics and delay students' engagement with college-level coursework" (Dana Center, 2016, p. 1). A student beginning the mathematics sequence through a non-corequisite developmental education course could take three semesters to pass a gateway mathematics course. This timeline may be extended based on low pass rates along the sequence. For example, data from the Florida College System align with national findings to indicate pass rates of 59 percent in developmental education, 57 percent in Intermediate Algebra, and 64 percent in College Algebra[2]. In addition, findings from research on Florida College System mathematics course enrollments of Associate in Arts students indicate nearly one-fifth of students did not enroll in a mathematics course during their first three years in college. When they did enroll, it was common for students to enroll in developmental education, Intermediate Algebra, or College Algebra in the fall semester and then never enroll in another mathematics class (Center for Postsecondary Success, 2018). In addition, researchers found no evidence that taking Intermediate Algebra increased the likelihood of passing College Algebra; in fact, success in College Algebra actually decreased for some students. This course sequence increases the time and cost of postsecondary education.

In 2013, Florida Senate Bill 1720 re-designed developmental education, requiring Florida College System institutions to implement a developmental education plan no later than fall 2014 and to make annual accountability reports on developmental education beginning in 2015; it specifies which students are

[1] Carnegie Math Pathways, The Charles A. Dana Center at the University of Texas at Austin, Transforming Post-Secondary Education in Mathematics (TPSEMath), Complete College America (CCA), National Association of System Heads (NASH), American Association of State Colleges and Universities (AASCU), and the Association of Public & Land-Grant Universities (APLU).

[2] For all course enrollments in 2016-17 academic year.

not required to be tested or to enroll in developmental education and requires colleges to provide students with developmental education options including in-course tutoring. The primary strategies implemented in developmental education, particularly compression and modularized, allow students to address skill deficiencies and possibly move to college level work within the same semester. Additionally, reducing the number of developmental courses and student attempts provides direct entry into college level work while raising standards and academically challenging students.

Secondly, the content of entry-level mathematics courses may not be aligned to the needs of today's college students, in terms of both their fields of study and workforce aspirations. In particular, "Professional mathematics associations strongly state that not all students need or benefit from the College Algebra-to Calculus pathway, which has been the default mathematics requirement in most places" (AMPSS, 2017, p. 9). The authors argue courses should focus more on statistics and quantitative reasoning that are grounded in context based learning and more applicable to academic majors and careers. Florida has taken initial steps towards better aligning courses with academic majors through Meta-Major Academic Pathways, which align required gateway mathematics courses with a students' intended academic and career goals[3]. The development of meta-majors was designed for students to more easily enter their chosen area of study, beginning with developmental education, if needed, as well as the appropriate courses to achieve their educational goals. Many colleges developed program maps affording students a suggested schedule for completing program requirements. In addition, data indicates students have higher pass rates in Liberal Arts Mathematics I, Liberal Arts Mathematics II, and Elementary Statistics, compared to College Algebra (Florida College System data, available through EdStats online data portal).

The following sections provide a brief overview of national research and Florida data related specifically to each of the three mathematics workgroups. Annotations are duplicated among sections when research was applicable to more than one workgroup. As the workgroups continue their work over the next year, additional data will be compiled and shared.

[3] Florida Rule, 6A-14.065 – Meta-Major Academic Pathways

Literature Review for Specific Workgroups

High School to College Alignment Workgroup

Connecting high school and college level mathematics is a key strategy to student success, which may include refocusing efforts to ensure high school students are ready for college level courses upon graduation, aligning meta-major pathways that start in high school and provide a clear path into college, utilizing the best predictors for college level mathematics placement, and educating high school and middle school students and parents on actions students can take in high school that lead to success in postsecondary mathematics. In Florida, 39.2 percent of public high school graduating seniors enrolled in Algebra I or an equivalent prior to 9th grade, but these percentages vary by district, from a low of under ten percent to over 80 percent. In addition, once students enter postsecondary education, the success of students, based on district, also varies considerably. For example, the passing rate of recent high school graduates passing an entry-level mathematics course for credit averages 73.2 percent, but ranges from a low of nearly 40 percent to a high of over 90 percent.

The following annotations outline research related to high school to college mathematics alignment:

Belfield and Crosta (2012) found high school GPA to be a "good and consistent" predictor of college performance (p. 39). The researchers noted a student's college GPA tends to be one grade notch below the same student's high school GPA. Therefore, if a student's high school GPA was a C+, the same student's college GPA is predicted to be a C, on average. The researchers recommended waiving college placement tests, including developmental education, for students with high school GPAs above the C+ threshold.

Hodara and Jaggars (2014) noted acceleration—enrollment in shorter versus longer developmental education sequences—may have unexpected positive side effects. The researchers indicated when testing acceleration, systems (i.e. divisions) and individual institutions may experience unexpected positive side effects, such as increased collaboration among college faculty and staff, stronger alignment across the developmental and college curriculum, increased communication with college students, and improved stakeholder relationships between high schools and colleges or between faculty and academic counselors.

Jaggars and Hodara (2013) identified system-wide consistency and institutional autonomy as one of three opposing forces shaping developmental education. The researchers found even within a system with "purportedly consistent entry standards" (p. 576), individual colleges can find ways to exert autonomy over their own developmental policies and programming. However, institutional autonomy diminishes common entry-level standards communicated to high schools about college-readiness. To combat this opposing force, the researchers recommended system-wide consistency must honor institutional autonomy.

Nix, Perez-Felkner, and Thomas (2015) found perceived mathematics ability in high school varies by gender and is highly predictive of selective majors in physics, engineering, math, and computer science (PEMC) as well as health science. Additionally, the researchers found students' perceptions of their mathematics and verbal abilities influence their retention in and selection of certain science, technology, engineering, and mathematics (STEM) majors. The researchers recommended high schools should (1) increase women's access to advanced scientific coursework and (2) implement strategies to decrease the influence of stereotype threat on women's pathways to scientific degrees.

Perez-Felkner, McDonald, Schneider, and Grogan (2012) found racial/ethnic and gender underrepresentation in STEM fields are interrelated. Race/ethnicity and gender factors influence female and racial/ethnic minority adolescents' pathways towards careers in STEM fields. Specifically, women and men's subjective orientations closely resemble. However, the effects of women's subjective orientations on the probability of majoring in PEMC vary by their high school mathematics course completion levels. For example, the researchers found women who take more mathematics courses in high school are more likely to major in PEMC fields. However, course taking alone does not reduce gender disparities in selecting PEMC majors. Moreover, high mathematics ability (measured by 10th grade standardized test scores) has a positive effect on women's selection of social, behavioral, clinical, and health science majors. However, high mathematics ability (measured by 10th grade standardized test scores) has a less robust association with the selection of PEMC fields. The researchers recommended high schools expand beyond simply encouraging women to take advanced coursework and doing well in them. For women and racial/ethnic minority students, high schools must create a holistic culture of support for these students to pursue and succeed in PEMC fields.

Scott-Clayton (2012) found the incremental validity of placement exams relative to high school background predictors of success is weak in both mathematics and English, but when high school GPA is accounted, the variation explained increases by about six percentage points in mathematics and less than two percentage points in English. The researcher recommended: (1) Using high school achievement alone reduces severe placement mistakes than using placement exams alone; (2) combining placement test scores, high school achievement, and selected background characteristics (i.e. years since high school graduation and whether a student is from a local high school) could reduce severe placement errors by about 15 percent in each subject and improve college-level success; and, (3) using students' best placement scores or an index of their high school background could "markedly lower the remediation rate without compromising college-level success rates" (p. 38).

Wang (2013a) found important heterogeneity in the effects of high school and higher education variables based on where students started their postsecondary education (i.e. community colleges or four-year institutions). Exposure to mathematics and science courses in high school have a strong influence on four-year beginners' STEM interests. However, the impact of mathematics and science courses in high school appears to have a positive yet smaller impact on community college beginners' STEM interests. Secondly, postsecondary academic integration and financial aid have differential effects on STEM entrance, accruing more to four-year beginners and less to community colleges beginners. The researcher recommended high schools should strengthen STEM learning and cultivate STEM interest, and postsecondary institutions should improve the academic integration and financial aid of STEM degree-seeking students.

Wang (2013b) found choosing a STEM major has a direct relationship with (1) intent to major in STEM, (2) high school mathematics achievement, and (3) initial postsecondary experiences, such as academic integration and financial aid. Moreover, influencing the largest impact on choosing a STEM major, intent to major in STEM is "directly affected by 12-grade mathematics achievement, exposure to mathematics and science courses, and mathematics self-efficacy—all three subject to the influence of early achievement in and attitudes toward math" (p. 1081). Additionally, the researcher found heterogeneous effects of mathematics achievement and exposure to mathematics and science across racial groups, indicating positive impacts on STEM intent accruing most to white students and least to underrepresented minority students. The researcher recommended high schools and postsecondary institutions play a vital role in strengthening mathematics achievement and cultivating STEM interest, especially for underrepresented minority students.

Wang, Sun, and Wickersham (2017) discussed the use of contextualization to improve mathematics remediation. Contextualization is "a diverse family of instructional strategies designed to more seamlessly link the learning of foundational skills and academic or occupational content by focusing teaching and learning squarely on concrete applications in a specific context that is of interest to the student" (p. 428). Employing Mazzeo's (2008) concept of contextualization and mixed method analyses (i.e. classroom observations, unstructured interviews, and quantitative data analysis), the researchers found: (1) When mathematics becomes "real and accessible," students overcome their fear of mathematics often resulting from a perceived mismatch between mathematics problems and their mathematics abilities; (2) through contextualization pedagogy, students begin to understand math's application; (3) through understanding comes appreciation for math's utility, especially regarding career aspirations; (4) through appreciating math, efficacy in mathematics becomes cultivated; and, (5) through the previous four steps, mathematics becomes larger than mathematics "clearly illuminated by the transformation in learning and motivational beliefs as voiced" by the students participating in the study (p. 458). The researchers recommended the five findings should ground the implementation of contextualization in mathematics curricula.

In the Florida College System, success rates in Intermediate Algebra 57 percent. Success rates in College Algebra, typically the next course in the mathematics sequence, are slightly above 60 percent (64%). By comparison, success rates are higher in Quantitative Reasoning (67%) and Pathway to Statistics (64%), as well as Liberal Arts Mathematics I (72%), Liberal Arts Mathematics II (69%), and Statistical Methods (70%).

Research from the Center for Postsecondary Success (CPS) at Florida State University (FSU), which studied the mathematics pathways of a cohort of FTIC Associate in Arts students, found that nearly one-fifth (19.2%) of students did not enroll in a mathematics course during their first three years in college. When they did enroll, it was common for students to enroll in developmental education (DE), MAT1033, or MAC1105 in the fall semester and then never enroll in another mathematics class. In addition, they found no evidence that taking MAT1033 as a prerequisite increased the likelihood of passing the gateway course, for some students, taking MAT1033 as a prerequisite to one of the gateway courses may actually *decrease* the likelihood of passing the gateway course, and for some students, enrolling in MAT1033 was associated with a *lower* likelihood of earning a degree within two years.

The following annotations outline research related to mathematics pathways in postsecondary education:

Belfield and Crosta (2012) found placement tests are not good predictors of: (1) Developmental education course grades, (2) English and mathematics gateway course grades, (3) credit accumulation, and (4) college GPA. However, unlike other pre-collegiate transcript information, the researchers found high school GPA to be a "good and consistent" predictor of college performance (p. 39). The researchers noted a student's college GPA tends to be one grade notch below the same student's high school GPA. Therefore, if a student's high school GPA was a C+, the same student's college GPA is predicted to be a C, on average. The researchers recommended waiving college placement tests, including developmental education, for students with high school GPAs above the C+ threshold.

Crandall and Soares (2015) found two themes to increase student attainment through course re-design: (1) Transition from a system-wide developmental education re-design to a system-wide gateway-course re-design, and (2) simultaneous legislative support through the Complete College Tennessee Act of 2010. Both activities contributed to the co-requisite model coordinating "developmental education courses with credit-bearing classes" (p. V). The researchers recommended five best practices for course re-design: (1) Recognize Context and Governance Structure Matter (through readiness for change, state and system policy convergence, governance structure, and institution context); (2) Use Data Analytics to Guide Innovation (through data collection, monitor and evaluation, and data sharing); (3) Create Space for Innovation (through business models and scalability of innovation); (4) Set Expectations (through frames of reference, expectation setting, and organizational structure and culture); and, (5) Promote Collective Action (through institutional leadership and information channels).

The **Dana Center (2016)** noted two drivers preventing student success in mathematics. The first driver inhibiting student success is mismatch of content. The Dana Center noted, "Traditional entry-level mathematics programs are not aligned with students' mathematical needs" (p. 3). The second driver preventing student success is long, multi-semester course sequences. According to the researchers, "Long developmental course sequences decrease students' chances of completing a credit-bearing mathematics course" (p. 4). The Dana Center recommended the following about mathematics pathways: (1) When evaluating mathematics pathways, the percent and number of students who earn

credit in a college-level mathematics course should appropriately be aligned to students' programs of study; (2) students' enrollment in mathematics pathways should reflect their intended programs of study; (3) a student's mathematics pathway should be based on their academic interests and goals, not on level of preparation; (4) with the exception of compelling reasons, underprepared students should "enter into accelerated pathways with a one-semester co-requisite model as the default" (p. 6); and, (5) all pathways should include accelerated structures, including the algebraic-intensive pathways leading to Calculus.

Hodara and Jaggars (2014) noted the impact of acceleration—enrollment in shorter versus longer developmental education sequences—on (1) access to introductory college coursework, (2) performance in that coursework, (3) overall college credit accumulation, and (4) degree attainment at the City University of New York (CUNY) community colleges. The researchers found accelerating students through developmental education in shorter sequences results in greater access to college-level coursework and long-term success, but acceleration may have consequences for student performance in college-level coursework. Second, acceleration has stronger impacts in English than math. Moreover, acceleration through developmental writing sequences has a positive effect on enrolling in and completing college English and has positive long-term impacts on college credit accumulation and degree attainment. Third, a shorter mathematics sequence does not translate into a positive long-term effect on college success. Non-STEM students at CUNY community colleges can delay developmental mathematics courses until the end of their program of study. Lastly, some CUNY community colleges required (and some did not require) the completion of developmental or college-level English in order to take key courses in the humanities, sciences, and social sciences. The researchers recommended (1) acceleration through shorter sequences is "a good starting point" to improve access to college-level coursework and, potentially, overall college success (p. 271).

Jaggars and Hodara (2013) identified (1) system-wide consistency versus institutional autonomy, (2) efficient versus effective assessment, and (3) promotion of student progression versus enforcement of academic standards as three opposing forces shaping developmental education. In the first opposing force (System-wide Consistency Versus Institutional Autonomy), the researchers found even within a system with "purportedly consistent entry standards" (p. 576), individual colleges can find ways to exert autonomy over their own developmental policies and programming. However, institutional autonomy diminishes common entry-level standards communicated to high schools about college-readiness. In the second opposing force (Efficient Versus Effective Assessment), the researchers found community colleges know standardized placement tests are imperfect, but the necessity of efficiently assessing and placing a high volume of students at the start of each semester makes colleges more hesitant to explore "more effective, but possibly, less efficient, alternatives" (p. 576). In the third opposing force (Promotion of Student Progression Versus Enforcement of Academic Standards), the researchers found initiatives aimed to support the access of students into college-level classes increase student enrollment in those courses. Faculty are reluctant of accelerated sequences and other strategies aimed to support student progression "due to concerns about academic quality" (p. 577). To combat these opposing forces, the researchers noted three recommendations: (1) System-wide consistency must honor institutional autonomy; (2) Assessment processes must be both efficient and effective; and, (3) Accelerated pathway standards must be maintained.

Martin (2017) recommended future research and workgroups should ask the following seven questions: "(1) How can we help at-risk students succeed? (2) How can we identify the needs of each student and personalize interventions and supports accordingly? (3) What can we do to make systems and institutions aware of evidence-based practices that work for all students, but particularly for those who are underrepresented, low-income and underprepared? (4) What is the evidence of impact for each intervention, and how can we use this information to scale up interventions in a resource-constrained environment?" (p. 39)..."(5) Who are the students at risk? (6) What are the indicators of high-quality,

equitable, and consistent delivery? (7) How do different interventions perform in different settings for different students?" (p. 41).

Rutschow and Diamond (2015) analyzed the development of the New Mathways Project (NMP)—created by the Dana Center in partnership with the Texas Association of Community Colleges—from spring 2012 through its first year of rollout at nine colleges in Texas in 2013-14, in addition to the student outcomes at the colleges before and during the first year. Comparing outcomes of student enrollment, persistence, and success in NMP and non-NMP courses, the researchers found the Dana Center helped initiate change in both two- and four-year colleges' mathematics requirements. As of 2014, 20 Texas community colleges offered at least one NMP course with descriptive outcome data revealing 30 percent of students completing both developmental and college-level courses in the first year. During the same period, only 8.3 percent of students enrolled in traditional developmental education courses. The researchers recommended the preparation and implementation of NMP-related strategies in other states.

Scott-Clayton (2012) found placement test scores are more predictive in mathematics than in English; mathematics test scores explain about 13 percent of the variation in first college-level mathematics course grades, while reading/writing scores explain less than two percent of the variation in first college-level English grades. Moreover, placement accuracy rates are higher in mathematics than in English (58 percent compared to 43 percent under a C criterion of success), and severe error rates are lower in mathematics than in English (24 percent compared to 33 percent). Additionally, the researcher found placement exams are more predictive of who is likely to do well in a college-level course than predicting who is likely to fail. The incremental validity of placement exams relative to high school background predictors of success is weak in both mathematics and English, but when high school GPA is accounted, the variation explained increase by about 6 percentage points in mathematics and less than 2 percentage points in English. The researcher recommended: (1) Using high school achievement alone reduces severe placement mistakes than using placement exams alone; (2) combining placement test scores, high school achievement, and selected background characteristics (i.e. years since high school graduation and whether a student is from a local high school) could reduce severe placement errors by about 15 percent in each subject and improve college-level success; and, (3) using students' best placement scores or an index of their high school background could "markedly lower the remediation rate without compromising college-level success rates" (p. 38).

The **Summit on Mathematics Pathways (2017)** highlighted a national guided pathways model, by Advancing Mathematics Pathways for Student Success (AMPSS), designed to implement mathematics pathways in at least four states in order to make significant impacts on student success. AMPSS is composed of mathematics professional societies, higher education leadership associations, and national education nonprofits that work directly with institutions and states. The guided pathways model is framed around a mapping system to help students navigate their way to and through higher education. The four key objectives of the mapping system are: (1) Clarify the Path, (2) Help Students Choose and Enter a Pathway, (3) Help Students Stay on the Path; and, (4) Ensure Students are Learning. The report recommended the guided pathways model will: (1) Ensure students are "appropriately placed and enrolled in the rigorous mathematics courses that are needed for their chosen program of study, rather than in mathematics courses such as College Algebra that they may not need" (p. 2); (2) be transferrable and relevant to specific programs of study at all institutions in a state; and, (3) help students to progress through an appropriate college-level mathematics course within one year of matriculation.

Wang (2013a) found important heterogeneity in the effects of high school and higher education variables based on where students started their postsecondary education (i.e. community colleges or four-year institutions). Exposure to mathematics and science courses in high school have a strong influence on four-year beginners' STEM interests. However, the impact of mathematics and science

courses in high school appears to have a positive yet smaller impact on community college beginners' STEM interests. Secondly, postsecondary academic integration and financial aid have differential effects on STEM entrance, accruing more to four-year beginners and less to community colleges beginners. The researcher recommended high schools should strengthen STEM learning and cultivate STEM interest, and postsecondary institutions should improve the academic integration and financial aid of STEM degree-seeking students.

Wang (2013b) found choosing a STEM major has a direct relationship with (1) intent to major in STEM, (2) high school mathematics achievement, and (3) initial postsecondary experiences, such as academic integration and financial aid. Moreover, influencing the largest impact on choosing a STEM major, intent to major in STEM is "directly affected by 12-grade mathematics achievement, exposure to mathematics and science courses, and mathematics self-efficacy—all three subject to the influence of early achievement in and attitudes toward math" (p. 1081). Additionally, the researcher found heterogeneous effects of mathematics achievement and exposure to mathematics and science across racial groups, indicating positive impacts on STEM intent accruing most to White students and least to underrepresented minority students. The researcher recommended high schools and postsecondary institutions play a vital role in strengthening mathematics achievement and cultivating STEM interest, especially for underrepresented minority students.

Wang (2016) found two main findings. First, the researcher found approximately "4.4% of the study sample transferred into 4-year STEM majors, 26.9% transferred into a 4-year non-STEM major, and 68.7% did not transfer to a 4-year institution" (p. 555). However, disparities existed in STEM and non-STEM transfer outcomes for female students, underrepresented racial minority students, single-parent students, first-generation students, non-traditional age students, and students with low high school GPAs—all groups were less likely to transfer upward into STEM or other areas of study. Secondly, the researcher found students who eventually transferred into four-year STEM fields "proportionately earned more credits within 'likely transferable' STEM and math, but less credits within, other course categories, than students with different transfer outcomes, both during the first year and throughout the 6-year period" (p. 555). Moreover, non-transfer students proportionately earned more credits from "likely terminal" STEM courses. The researcher recommended: (1) The importance of cultivating a more structured and tangible path of course-taking leading to successful STEM transfers; (2) the removal of stereotypes, misconceptions, and hostile campus environments about STEM fields, especially for underrepresented students; and, (3) improved transfer and articulation policies "within and beyond STEM programs across and between 2- and 4-year institutions" (p. 566).

Wang, Sun, Lee, and Wagner (2017) found the predicted probability of intending to transfer into STEM fields versus no transfer intent "increased by .036 when the active learning score increased by 1 point from its mean" (p. 608). However, the researchers found no significant relationship between active learning and students' intent to transfer into non-STEM majors compared to no transfer intent. Moreover, active learning has an indirect positive effect on transfer intent through its positive influence on transfer self-efficacy. The researchers recommended: (1) Institutional curriculum administrators should have open communication within their departments and conduct assessments to examine whether and how active learning is practiced in classrooms; (2) professional development opportunities should be offered within and across academic departments "as a means of ensuring that all instructors are equipped with the knowledge and skills to cultivate engaging lessons for their students" (p. 612-613); (3) administrators and department leaders should communicate the motivational benefits of active learning at all departmental and faculty gatherings; and, (4) two-year institutions should strategically and intentionally engage their part-time and contingent faculty.

Wang, Sun, and Wickersham (2017) discussed the use of contextualization to improve mathematics remediation. Contextualization is "a diverse family of instructional strategies designed to more

seamlessly link the learning of foundational skills and academic or occupational content by focusing teaching and learning squarely on concrete applications in a specific context that is of interest to the student" (p. 428). Employing Mazzeo's (2008) concept of contextualization and mixed method analyses (i.e. classroom observations, unstructured interviews, and quantitative data analysis), the researchers found: (1) When mathematics becomes "real and accessible," students overcome their fear of mathematics often resulting from a perceived mismatch between mathematics problems and their mathematics abilities; (2) through contextualization pedagogy, students begin to understand math's application; (3) through understanding comes appreciation for math's utility, especially regarding career aspirations; (4) through appreciating math, efficacy in mathematics becomes cultivated; and, (5) through the previous four steps, mathematics becomes larger than mathematics "clearly illuminated by the transformation in learning and motivational beliefs as voiced" by the students participating in the study (p. 458). The researchers recommended the five findings should ground the implementation of contextualization in mathematics curricula.

Wang, Wang, Wickersham, Sun, and Chan (2017) found completing mathematics requirements at earlier (e.g., first semester) or later (e.g., four or fifth semester) stages of college are related to a higher rate of credential completion. Additionally, the researchers found students who engage in (1) active learning, (2) find academics challenging, and (3) feel academically supported are more likely to complete a credential. However, student-faculty interactions are negatively related to credential completion. The researchers recommended: (1) Fulfilling college-level mathematics requirements early produces higher odds of credential completion; and, (2) community colleges can better assist their students by planning educational pathways, programs, and services that prevent students from struggling through necessary mathematics requirements, therefore maximizing their overall success.

Florida College System transfers account for around half of the State University System's upper division, traditionally students of junior and senior level academic standing. In addition, FCS transfers perform as well as native university students (2.9 GPA for FCS transfer students compared to a 3.1 GPA for SUS native students). The SUS discipline with the highest number of FCS transfer students include Business/Management (20% - 21,276 students), Health Sciences (12% - 12,385 students) and Psychology (8% - 9,057 students). Education, Engineering, and Life Sciences each account for between six and seven percent of enrollments. Therefore, together, these six disciplines enroll two-thirds (67%) of FCS transfer students. Understanding and documenting the different mathematics pathways for these disciplines will be key to providing guided pathways for our students.

The following annotations outline research related to mathematics pathways for postsecondary students, including students transferring institutions:

Belfield and Crosta (2012) found placement tests are not good predictors of: (1) Developmental education course grades, (2) English and mathematics gateway course grades, (3) credit accumulation, and (4) college GPA. However, unlike other pre-collegiate transcript information, the researchers found high school GPA to be a "good and consistent" predictor of college performance (p. 39). The researchers noted a student's college GPA tends to be one grade notch below the same student's high school GPA. Therefore, if a student's high school GPA was a C+, the same student's college GPA is predicted to be a C, on average. The researchers recommended waiving college placement tests, including developmental education, for students with high school GPAs above the C+ threshold.

Hodara and Jaggars (2014) noted the impact of acceleration—enrollment in shorter versus longer developmental education sequences—on (1) access to introductory college coursework, (2) performance in that coursework, (3) overall college credit accumulation, and (4) degree attainment at the City University of New York (CUNY) community colleges. The researchers found accelerating students through developmental education in shorter sequences results in greater access to college-level coursework and long-term success, but acceleration may have consequences for student performance in college-level coursework. Second, acceleration has stronger impacts in English than math. Moreover, acceleration through developmental writing sequences has a positive effect on enrolling in and completing college English and has positive long-term impacts on college credit accumulation and degree attainment. Third, a shorter mathematics sequence does not translate into a positive long-term effect on college success. Non-STEM students at CUNY community colleges can delay developmental mathematics courses until the end of their program of study. Lastly, some CUNY community colleges required (and some did not require) the completion of developmental or college-level English in order to take key courses in the humanities, sciences, and social sciences. The researchers recommended (1) acceleration through shorter sequences is "a good starting point" to improve access to college-level coursework and, potentially, overall college success (p. 271).

Jaggars and Hodara (2013) identified (1) system-wide consistency versus institutional autonomy, (2) efficient versus effective assessment, and (3) promotion of student progression versus enforcement of academic standards as three opposing forces shaping developmental education. In the first opposing force (System-wide Consistency Versus Institutional Autonomy), the researchers found even within a system with "purportedly consistent entry standards" (p. 576), individual colleges can find ways to exert autonomy over their own developmental policies and programming. However, institutional autonomy diminishes common entry-level standards communicated to high schools about college-readiness. In the second opposing force (Efficient Versus Effective Assessment), the researchers found community colleges know standardized placement tests are imperfect, but the necessity of efficiently assessing and placing a high volume of students at the start of each semester makes colleges more hesitant to explore

"more effective, but possibly, less efficient, alternatives" (p. 576). In the third opposing force (Promotion of Student Progression Versus Enforcement of Academic Standards), the researchers found initiatives aimed to support the access of students into college-level classes increase student enrollment in those courses. Faculty are reluctant of accelerated sequences and other strategies aimed to support student progression "due to concerns about academic quality" (p. 577). To combat these opposing forces, the researchers noted three recommendations: (1) System-wide consistency must honor institutional autonomy; (2) Assessment processes must be both efficient and effective; and, (3) Accelerated pathway standards must be maintained.

Rutschow and Diamond (2015) analyzed the development of the New Mathways Project (NMP)—created by the Dana Center in partnership with the Texas Association of Community Colleges—from spring 2012 through its first year of rollout at nine colleges in Texas in 2013-14, in addition to the student outcomes at the colleges before and during the first year. Comparing outcomes of student enrollment, persistence, and success in NMP and non-NMP courses, the researchers found the Dana Center helped initiate change in both two- and four-year colleges' mathematics requirements. As of 2014, 20 Texas community colleges offered at least one NMP course with descriptive outcome data revealing 30 percent of students completing both developmental and college-level courses in the first year. During the same period, only 8.3 percent of students enrolled in traditional developmental education courses. The researchers recommended the preparation and implementation of NMP-related strategies in other states.

Scott-Clayton (2012) found placement test scores are more predictive in mathematics than in English; mathematics test scores explain about 13 percent of the variation in first college-level mathematics course grades, while reading/writing scores explain less than two percent of the variation in first college-level English grades. Moreover, placement accuracy rates are higher in mathematics than in English (58 percent compared to 43 percent under a C criterion of success), and severe error rates are lower in mathematics than in English (24 percent compared to 33 percent). Additionally, the researcher found placement exams are more predictive of who is likely to do well in a college-level course than predicting who is likely to fail. The incremental validity of placement exams relative to high school background predictors of success is weak in both mathematics and English, but when high school GPA is accounted, the variation explained increase by about 6 percentage points in mathematics and less than 2 percentage points in English. The researcher recommended: (1) Using high school achievement alone reduces severe placement mistakes than using placement exams alone; (2) combining placement test scores, high school achievement, and selected background characteristics (i.e. years since high school graduation and whether a student is from a local high school) could reduce severe placement errors by about 15 percent in each subject and improve college-level success; and, (3) using students' best placement scores or an index of their high school background could "markedly lower the remediation rate without compromising college-level success rates" (p. 38).

The **Summit on Mathematics Pathways (2017)** highlighted a national guided pathways model, by Advancing Mathematics Pathways for Student Success (AMPSS), designed to implement mathematics pathways in at least four states in order to make significant impacts on student success. AMPSS is composed of mathematics professional societies, higher education leadership associations, and national education nonprofits that work directly with institutions and states. The guided pathways model is framed around a mapping system to help students navigate their way to and through higher education. The four key objectives of the mapping system are: (1) Clarify the Path, (2) Help Students Choose and Enter a Pathway, (3) Help Students Stay on the Path; and, (4) Ensure Students are Learning. The report recommended the guided pathways model will: (1) Ensure students are "appropriately placed and enrolled in the rigorous mathematics courses that are needed for their chosen program of study, rather than in mathematics courses such as College Algebra that they may not need" (p. 2); (2) be transferrable

and relevant to specific programs of study at all institutions in a state; and, (3) help students to progress through an appropriate college-level mathematics course within one year of matriculation.

Wang (2013a) found important heterogeneity in the effects of high school and higher education variables based on where students started their postsecondary education (i.e. community colleges or four-year institutions). Exposure to mathematics and science courses in high school have a strong influence on four-year beginners' STEM interests. However, the impact of mathematics and science courses in high school appears to have a positive yet smaller impact on community college beginners' STEM interests. Secondly, postsecondary academic integration and financial aid have differential effects on STEM entrance, accruing more to four-year beginners and less to community colleges beginners. The researcher recommended high schools should strengthen STEM learning and cultivate STEM interest, and postsecondary institutions should improve the academic integration and financial aid of STEM degree-seeking students.

Wang (2013b) found choosing a STEM major has a direct relationship with (1) intent to major in STEM, (2) high school mathematics achievement, and (3) initial postsecondary experiences, such as academic integration and financial aid. Moreover, influencing the largest impact on choosing a STEM major, intent to major in STEM is "directly affected by 12-grade mathematics achievement, exposure to mathematics and science courses, and mathematics self-efficacy—all three subject to the influence of early achievement in and attitudes toward math" (p. 1081). Additionally, the researcher found heterogeneous effects of mathematics achievement and exposure to mathematics and science across racial groups, indicating positive impacts on STEM intent accruing most to White students and least to underrepresented minority students. The researcher recommended high schools and postsecondary institutions play a vital role in strengthening mathematics achievement and cultivating STEM interest, especially for underrepresented minority students.

Wang (2016) found two main findings. First, the researcher found approximately "4.4% of the study sample transferred into 4-year STEM majors, 26.9% transferred into a 4-year non-STEM major, and 68.7% did not transfer to a 4-year institution" (p. 555). However, disparities existed in STEM and non-STEM transfer outcomes for female students, underrepresented racial minority students, single-parent students, first-generation students, non-traditional age students, and students with low high school GPAs—all groups were less likely to transfer upward into STEM or other areas of study. Secondly, the researcher found students who eventually transferred into four-year STEM fields "proportionately earned more credits within 'likely transferable' STEM and math, but less credits within, other course categories, than students with different transfer outcomes, both during the first year and throughout the 6-year period" (p. 555). Moreover, non-transfer students proportionately earned more credits from "likely terminal" STEM courses. The researcher recommended: (1) The importance of cultivating a more structured and tangible path of course-taking leading to successful STEM transfers; (2) the removal of stereotypes, misconceptions, and hostile campus environments about STEM fields, especially for underrepresented students; and, (3) improved transfer and articulation policies "within and beyond STEM programs across and between 2- and 4-year institutions" (p. 566).

Wang, Sun, Lee, and Wagner (2017) found the predicted probability of intending to transfer into STEM fields versus no transfer intent "increased by .036 when the active learning score increased by 1 point from its mean" (p. 608). However, the researchers found no significant relationship between active learning and students' intent to transfer into non-STEM majors compared to no transfer intent. Moreover, active learning has an indirect positive effect on transfer intent through its positive influence on transfer self-efficacy. The researchers recommended: (1) Institutional curriculum administrators should have open communication within their departments and conduct assessments to examine whether and how active learning is practiced in classrooms; (2) professional development opportunities should be offered within and across academic departments "as a means of ensuring that all instructors

are equipped with the knowledge and skills to cultivate engaging lessons for their students" (p. 612-613); (3) administrators and department leaders should communicate the motivational benefits of active learning at all departmental and faculty gatherings; and, (4) two-year institutions should strategically and intentionally engage their part-time and contingent faculty.

Wang, Sun, and Wickersham (2017) discussed the use of contextualization to improve mathematics remediation. Contextualization is "a diverse family of instructional strategies designed to more seamlessly link the learning of foundational skills and academic or occupational content by focusing teaching and learning squarely on concrete applications in a specific context that is of interest to the student" (p. 428). Employing Mazzeo's (2008) concept of contextualization and mixed method analyses (i.e. classroom observations, unstructured interviews, and quantitative data analysis), the researchers found: (1) When mathematics becomes "real and accessible," students overcome their fear of mathematics often resulting from a perceived mismatch between mathematics problems and their mathematics abilities; (2) through contextualization pedagogy, students begin to understand math's application; (3) through understanding comes appreciation for math's utility, especially regarding career aspirations; (4) through appreciating math, efficacy in mathematics becomes cultivated; and, (5) through the previous four steps, mathematics becomes larger than mathematics "clearly illuminated by the transformation in learning and motivational beliefs as voiced" by the students participating in the study (p. 458). The researchers recommended the five findings should ground the implementation of contextualization in mathematics curricula.

Florida Data to Support Workgroups

To support the work of the Mathematics Workshops, relevant state and college-wide data have been complied. The following provides a brief overview of the resources available in the Canvas folders, or online through business intelligence tools. The resources below are organized by workgroup and the text in **Bold** corresponds to the documents file name in Canvas.

High School to College Alignment Workgroup

- **Mathematics Pathways in the Florida College System (CPS).** A recent Center for Postsecondary Success report (February 2018) investigated mathematics pathways by examining Associate in Arts (AA) students' course taking behavior and success in Intermediate Algebra (MAT1033) and College Algebra (MAC1105), as well as their degree completion in the Florida College System. The report did not find evidence that taking MAT1033 as a prerequisite to MAC1105 increased the likelihood of passing the gateway course (MAC1105), and for some students taking MAT1033 as a prerequisite may actually decrease the likelihood of passing the gateway course. Further, the report found that enrolling in MAT1033 was associated with a lower likelihood of earning a degree within two years, a result of additional coursework beyond the minimum AA requirements.

- **Short-Term Success in Mathematics Pathways in the Florida College System (CPS).** This is a follow-up document with additional information, based on the work for the Mathematics Pathways in the Florida College System report, listed above.

Data Tool

- **Florida High School Feedback Report.** Each year, Florida publishes measures to indicate how well high school graduates are prepared for postsecondary education. To assist school districts in preparing Florida's high school graduates for successful transition to postsecondary education and the workplace, the High School Feedback Report provides a snapshot of the 2016 high school graduates' academic experience. These reports provide enrollment, participation and performance data to help districts and schools answer the question, "How effectively are we preparing students for success in a postsecondary education program?" Every public high school that had graduates in 2016 has an online report. Within the report format are pre- and post-graduation indicators of college readiness, allowing for comparison of school, district and state-level data. Particular data relevant to the mathematics workshop include:
    - Percent of graduates who scored level three or better on the Algebra 1 EOC
    - Percent of graduates who completed at least one dual enrollment mathematics course
    - Percent of graduates who completed at least one level three high school mathematics course
    - Percent of graduates with standard high school diploma who took the SAT / ACT / CPT / PERT, entered a public college or university in Florida in the year following graduation, and scored at or above college-level cut scores in math
    - Of the graduates enrolled in a mathematics course in Florida in the fall, the percent who successfully completed Remedial Mathematics (non-college credit)
    - Of the graduates enrolled in a mathematics course in Florida in the fall, the percent who successfully completed Intermediate Algebra (for elective credit)
    - Of the graduates enrolled in a mathematics course in Florida in the fall, the percent who successfully completed entry-level mathematics (for mathematics credit)
    - Of the graduates enrolled in a mathematics course in Florida in the fall, the percent who successfully completed Advanced Math

Florida College System Mathematics Sequences Workgroup

- **Mathematics Pathways in the Florida College System (CPS).** A recent Center for Postsecondary Success report (February 2018) investigated mathematics pathways by examining Associate in Arts (AA) students' course taking behavior and success in Intermediate Algebra (MAT1033) and College Algebra (MAC1105), as well as their degree completion in the Florida College System. The report did not find evidence that taking MAT1033 as a prerequisite to MAC1105 increased the likelihood of passing the gateway course (MAC1105), and for some students taking MAT1033 as a prerequisite may actually decrease the likelihood of passing the gateway course. Further, the report found that enrolling in MAT1033 was associated with a lower likelihood of earning a degree within two years, a result of additional coursework beyond the minimum AA requirements.

- **Short-Term Success in Mathematics Pathways in the Florida College System (CPS).** This is a follow-up document with additional information, based on the work for the Mathematics Pathways in the Florida College System report, list above.

- **Mathematics Enrollment and Pass Rates (FCS)**. This dashboard highlights enrollment and pass rates for developmental education, perquisite courses, and gateway mathematics courses over three years, 2014-15 to 2016-17. Most notably, pass rates for MAT1033 are below 60 percent.

- **Student Success by First Mathematics Course Enrollment (FCS).** This dashboard highlights student success for a cohort of first-time, full-time (FTIC) students in the fall of 2014, who were enrolled in an Associate in Arts program, and enrolled in a mathematics course in the fall semester. This analysis was conducted to determine how likely students were to pass a mathematics Gateway course within two years of first enrolling in college. Of the students in the analysis who started in developmental education, only 33 percent passed a Gateway course and only 56 percent of students who started in a prerequisite mathematics course did so.

Data Tool

- **Florida's Pk-20 Educational Information Portal (EdStats)**. EdStats connects people with reports and statistical information about: (1) PK-12 Public Schools, (2) Florida College System, (3) Outcomes Data, and (4) Workforce Data. Each of the four areas provides access to standard and interactive reports that provide overall and demographic information in a variety of formats including graphs, tables, maps and custom reports based on your interests in education-related data. Florida College System reports include enrollment and course outcome data on developmental education, gateway, and core course, and allow users to disaggregate data by specific college, course, race/ethnicity, age, and economic status.

Florida College System to University Alignment Workgroup

- **Florida College System Articulation Table Summary (SUS)**. The FCS articulation reports provide information on the performance of FCS transfers in the State University System. The Table Summary document compares a number of data elements for FCS transfers and SUS students, including headcount, GPA, credit hours per term, and credit hours to degree. In particular, for the mathematics workgroups, it also details the data by discipline, allowing for a review of STEM vs. non STEM disciples, and the impact of mathematics on these results.

- **Florida College System Articulation Table 14 (SUS)**. The FCS articulation reports provide information on the performance of FCS transfers in the State University System. Table 14 provides information on the GPA of FCS transfers student by discipline at each of the SUS institutions, allowing for a review of STEM vs. non STEM disciples, and the impact of mathematics on these results.

- **SUS Admissions Data for FCS Transfers - System Level (SUS)**. This table provides the most recent, system-level data on the number of FCS Associate in Arts graduates who applied, were admitted, and enrolled in a State University System institution.

- **FCS Transfer Admission Data into the SUS (SUS)**. This document provides data on the number of FCS transfer students who applied, were admitted, and enrolled in a SUS institution (at the system level and at each SUS institution) for the fall 2016. The data are also separated by AA and Non-AA transfers.

- **FCS Transfer GPAs (SUS).** This document outlines the GPA (five-year average) of SUS Native FTIC students compared to FCS Transfers (with AA degree, with AS degree, or with no degree), by SUS institution and FCS institution of transfer.

Annotated Bibliography

Belfield, C. R., & Crosta, P. M. (2012, February). ***Predicting success in college: The importance of placement tests and high school transcripts*** **(CCRC Working Paper No. 42). New York, NY: Community College Research Center, Teachers College, Columbia University.**

TYPE: Report

KEYWORDS: Mathematics pathway, placement tests

RELEVANT WORKGROUP(S): High School to College Alignment, FCS Mathematics Sequences, FCS to Univ. Alignment

This report uses student-level data from a statewide community college system to examine the validity of placement tests and high school information in predicting course grades and college performance. Specifically, the researchers examined the ACCUPLACER and COMPASS placement tests. Employing a correlation analysis and a replication of Scott-Clayton's (2010) formal framework, the researchers found placement tests are not good predictors of: (1) Developmental education course grades, (2) English and mathematics gateway course grades, (3) credit accumulation, and (4) college GPA. However, unlike other pre-collegiate transcript information, the researchers found high school GPA to be a "good and consistent" predictor of college performance (p. 39). The researchers noted a student's college GPA tends to be one grade notch below the same student's high school GPA. Therefore, if a student's high school GPA was a C+, the same student's college GPA is predicted to be a C, on average. The researchers recommended waiving college placement tests, including developmental education, for students with high school GPAs above the C+ threshold.

Crandall, J. R., & Soares, L. (2015). ***The architecture of innovation: System-level course re-design in Tennessee*****. Washington, DC: American Council on Education.**

TYPE: Report

KEYWORDS: Mathematics pathway, re-design, development, gateway, leading change

RELEVANT WORKGROUP(S): FCS Mathematics Sequences

This report examines the success of Tennessee Board of Regents (TBR)'s two curricular re-designs: (1) The 2006-09 Developmental Studies Re-design (DSR) and (2) the 2014-Present Course Revitalization Re-design. Employing a case study analysis and Kotter's (2012) leading change framework, the researchers found two themes illustrating TBR's commitment to increase student attainment through course re-design: (1) Transition from a system-wide developmental education re-design to a system-wide gateway-course re-design, and (2) simultaneous legislative support through the Complete College Tennessee Act of 2010. Both activities contributed to the co-requisite model coordinating "developmental education courses with credit-bearing classes" (p. V). The researchers recommended five best practices for course re-design: (1) Recognize Context and Governance Structure Matter (through readiness for change, state and system policy convergence, governance structure, and institution context); (2) Use Data Analytics to Guide Innovation (through data collection, monitor and evaluation, and data sharing); (3) Create Space for Innovation (through business models and scalability of innovation); (4) Set Expectations (through frames of reference, expectation setting, and organizational structure and culture); and, (5) Promote Collective Action (through institutional leadership and information channels).

Appendix A includes:

- TBR Request for Proposal (Box 1)
- Kotter's (2012) Eight-Stage Change Process (Box 2)
- The Architecture of Innovation: System-Level Course Re-design in Tennessee (Figure 3)
- Austin Peay State University Developmental Studies Re-design (Figure 4)
- Chattanooga State Community College (Figure 5)

Dana Center. (2016, October). *The case for mathematics pathways*. Austin, TX: Charles A. Dana Center.

TYPE: Report

KEYWORDS: Mathematics pathways

RELEVANT WORKGROUP(S): FCS Mathematics Sequences

In this report, the Dana Center argued mathematics pathways are solutions to dismantle two structural drivers preventing student success. The first driver inhibiting student success is mismatch of content. The Dana Center noted, "Traditional entry-level mathematics programs are not aligned with students' mathematical needs" (p. 3). The second driver preventing student success is long, multi-semester course sequences. According to the researchers, "Long developmental course sequences decrease students' chances of completing a credit-bearing mathematics course" (p. 4). The Dana Center recommended the following about mathematics pathways: (1) When evaluating mathematics pathways, the percent and number of students who earn credit in a college-level mathematics course should appropriately be aligned to students' programs of study; (2) students' enrollment in mathematics pathways should reflect their intended programs of study; (3) a student's mathematics pathway should be based on their academic interests and goals, not on level of preparation; (4) with the exception of compelling reasons, underprepared students should "enter into accelerated pathways with a one-semester co-requisite model as the default" (p. 6); and, (5) all pathways should include accelerated structures, including the algebraic-intensive pathways leading to Calculus.

Appendix B includes:

- Drivers that Create Barriers for Students (Figure 1)

Hodara, M., & Jaggars, S. S. (2014). An examination of the impact of accelerating community college students' progression through developmental education. *Journal of Higher Education, 85*(2), 246-276.

TYPE: Peer-Reviewed Article

KEYWORDS: Mathematics pathways, acceleration, community college, developmental education

RELEVANT WORKGROUP(S): High School to College Alignment, FCS Mathematics Sequences, FCS to Univ. Alignment

This peer-reviewed article examines the impact of a basic form of acceleration—enrollment in shorter versus longer developmental education sequences—on (1) access to introductory college coursework, (2) performance in that coursework, (3) overall college credit accumulation, and (4) degree attainment at the City University of New York (CUNY) community colleges. Employing a simple logistic regression analysis and propensity score matching, the researchers found four main findings. First, accelerating students through developmental education in shorter sequences results in greater access to college-level coursework and long-term success, but acceleration may have consequences for student performance in college-level coursework. Second, acceleration has stronger impacts in English than math. Moreover, acceleration through developmental writing sequences has a positive effect on enrolling in and completing college English and has positive long-term impacts on college credit accumulation and degree attainment. Third, a shorter mathematics sequence does not translate into a positive long-term effect on college success. Non-STEM students at CUNY community colleges can delay developmental mathematics courses until the end of their program of study. Lastly, some CUNY community colleges required (and some did not require) the completion of developmental or college-level English in order to take key courses in the humanities, sciences, and social sciences. The researchers recommended (1) acceleration through shorter sequences is "a good starting point" to improve access to college-level coursework and, potentially, overall college success (p. 271); and, (2) when testing acceleration, systems and individual institutions may experience unexpected positive side effects (e.g., increased collaboration among faculty and staff, stronger alignment across the developmental and college curriculum, increased communication with students, and improved stakeholder relationships between high schools and colleges or between faculty and academic counselors).

Jaggars, S. S., & Hodara, M. (2013). The opposing forces that shape developmental education. *Community College Journal of Research and Practice, 37*(7), 575-579.

TYPE: Peer-Reviewed Article

KEYWORDS: Opposing forces, accelerated sequences

RELEVANT WORKGROUP(S): High School to College Alignment, FCS Mathematics Sequences, FCS to Univ. Alignment

This peer-reviewed article identified three underlying issues, possibly, preventing colleges' efforts to improve developmental outcomes. The underlying issues are: (1) System-wide consistency versus institutional autonomy, (2) Efficient versus effective assessment, and (3) Promotion of student progression versus enforcement of academic standards. The researchers employed an opposing forces framework, interviewed 67 college administrators and faculty at an urban community college system where over 80 percent of students are assigned to at least one developmental course, and examined documents on developmental policy and programming (i.e. policy memoranda, testing center and degree program webpages, and course catalogs). In the first opposing force (System-wide Consistency Versus Institutional Autonomy), the researchers found even within a system with "purportedly consistent entry standards" (p. 576), individual colleges can find ways to exert autonomy over their own developmental policies and programming. However, institutional autonomy diminishes common entry-level standards communicated to high schools about college-readiness. In the second opposing force (Efficient Versus Effective Assessment), the researchers found community colleges know standardized placement tests are imperfect, but the necessity of efficiently assessing and placing a high volume of students at the start of each semester makes colleges more hesitant to explore "more effective, but possibly, less efficient, alternatives" (p. 576). In the third opposing force (Promotion of Student Progression Versus Enforcement of Academic Standards), the researchers found initiatives aimed to support the access of students into college-level classes increase student enrollment in those courses. Faculty are reluctant of accelerated sequences and other strategies aimed to support student progression "due to concerns about academic quality" (p. 577). To combat these opposing forces, the researchers noted three recommendations: (1) System-wide consistency must honor institutional autonomy; (2) Assessment processes must be both efficient and effective; and, (3) Accelerated pathway standards must be maintained.

Martin, R. R. (2017, January/February). Taking student success to scale [TS³]. *Change: The Magazine of Higher Learning, 49*(1), 38-47.

TYPE: Report

KEYWORDS: Mathematics pathways

RELEVANT WORKGROUP(S): FCS Mathematics Sequences

In addition to other topics, this short report notes re-designing mathematics pathways is a strategy for improving the success of underprepared college students.

The researcher posited,

> "A prominent barrier to student success, especially for underrepresented, low-income, and first-generation students, is a lack of information. Predictive analytics and data-mining techniques have proven to be powerful methods of empowering and informing students. The focus of this initiative is on implementing predictive analytics across multiple systems, strengthening the data infrastructure needed to leverage these tools, and implementing the policy, curricular advances, and academic support programs needed to enable the successful use of predictive analytics (Denley, 2014" (p. 41)

Moreover, the researcher recommended future research and workgroups should ask the following seven questions: "(1) How can we help at-risk students succeed? (2) How can we identify the needs of each student and personalize interventions and supports accordingly? (3) What can we do to make systems and institutions aware of evidence-based practices that work for all students, but particularly for those who are underrepresented, low-income and underprepared? (4) What is the evidence of impact for each intervention, and how can we use this information to scale up interventions in a resource-constrained environment?" (p. 39)..."(5) Who are the students at risk? (6) What are the indicators of high-quality, equitable, and consistent delivery? (7) How do different interventions perform in different settings for different students?" (p. 41).

Appendix C includes:

- TS³ Metrics (Figure 6)

Nix, S., Perez-Felkner, L., & Thomas, K. (2015). Perceived mathematical ability under challenge: A longitudinal perspective on sex segregation among STEM degree fields. *Frontiers in Psychology, 6*(530), 1-19.

TYPE: Peer-Reviewed Article

KEYWORDS: Mathematics perceptions, higher education, gender, STEM, pipeline, perceived ability, ability-related beliefs, college major

RELEVANT WORKGROUP(S): High School to College Alignment

This peer-reviewed article examined the impact of students' perceptions of their mathematics ability on entry into the most sex-segregated and mathematics intensive undergraduate degrees: Physics, engineering, math, and computer science (PEMC). The researchers used nationally representative Education Longitudinal Study of 2002 (ELS:2002) data. Employing Adjusted Wald Tests, logistic regressions, and multiple logistics regressions, the researchers found perceived mathematics ability in high school varies by gender, and it is highly predictive of selective PEMC and health science majors. The researchers found women's 12th grade perceptions of their mathematics ability has a positive effect on their probability of selecting PEMC majors over and above biology. Moreover, gender moderates the effect of growth mindset on students' selection of health science majors. Additionally, the researchers found students' perceptions of their mathematics and verbal abilities influence their retention in and selection of certain STEM majors. The researchers recommended high schools should (1) increase women's access to advanced scientific coursework and (2) implement strategies to decrease the influence of stereotype threat on women's pathways to scientific degrees.

Appendix D includes:

- Conceptual Model of How Gender Moderates Perceived Ability and Major Choice (Figure 1)

Perez-Felkner, L., McDonald, S., Schneider, B., & Grogan, E. (2012). Female and male adolescents' subjective orientations to mathematics and the influence of those orientations on postsecondary majors. *Developmental Psychology, 48*(6), 1658-1673.

TYPE: Peer-Reviewed Article

KEYWORDS: Mathematics perceptions, gender, postsecondary education, social psychology, career, mathematics

RELEVANT WORKGROUP(S): High School to College Alignment

This peer-reviewed article examined the effects of adolescents' (1) subjective orientation, (2) course taking, and (3) academic performance on the likelihood of majoring in physics, engineering, math, and computer science (PEMC) fields. The researchers used nationally representative Educational Longitudinal Study of 2002 (ELS:2002) data. Employing hierarchical linear models (HLM) and odds ratios, the researchers found racial/ethnic and gender underrepresentation in science, technology, engineering, and mathematics (STEM) fields are interrelated. Race/ethnicity and gender factors influence female and racial/ethnic minority adolescents' pathways towards careers in STEM fields. Specifically, women and men's subjective orientations closely resemble. However, the effects of women's subjective orientations on the probability of majoring in PEMC vary by their high school mathematics course completion levels. For example, the researchers found women who take more mathematics courses in high school are more likely to major in PEMC fields. However, course taking alone does not reduce gender disparities in selecting PEMC majors. Moreover, high mathematics ability (measured by 10th grade standardized test scores) has a positive effect on women's selection of social, behavioral, clinical, and health science majors. However, high mathematics ability (measured by 10th grade standardized test scores) has a less robust association with the selection of PEMC fields. The researchers recommended high schools expand beyond simply encouraging women to take advanced coursework and doing well in them. For women and racial/ethnic minority students, high schools must create a holistic culture of support for these students to pursue and succeed in PEMC fields.

Rutschow, E. Z., & Diamond, J. (2015, April). ***Laying the foundations: Early findings from the New Mathways Project*****. Oakland, CA: MDRC.**

TYPE: Report

KEYWORDS: Mathematics pathways, re-design

RELEVANT WORKGROUP(S): FCS Mathematics Sequences, FCS to Univ. Alignment

This report analyzes the development of the New Mathways Project (NMP)—created by the Dana Center in partnership with the Texas Association of Community Colleges—from spring 2012 through its first year of rollout at nine colleges in Texas in 2013-14, in addition to the student outcomes at the colleges before and during the first year. The researchers employed mixed methods: (1) Observations of Dana Center trainings and meetings preparing for implementation; (2) site visits to all nine codevelopment colleges; (3) interviews, focus groups, and classroom observations at the colleges in spring 2013 (preparation), fall 2013 (first semester of implementation with the introduction of the Foundations and Framework courses), and spring 2014 (second semester of implementation with the introduction of the college-level statistics courses); and, (4) collection of various types of student and faculty data (i.e. student and faculty demographic characteristics, students' developmental placement levels, course enrollment and completion, and degree and certificate attainment). Comparing outcomes of student enrollment, persistence, and success in NMP and non-NMP courses, the researchers found the Dana Center helped initiate change in both two- and four-year colleges' mathematics requirements. As of 2014, 20 Texas community colleges offered at least one NMP course with descriptive outcome data revealing 30 percent of students completing both developmental and college-level courses in the first year. During the same period, only 8.3 percent of students enrolled in traditional developmental education courses. The researchers recommended the preparation and implementation of NMP-related strategies in other states.

Appendix E includes:

- A Comparison of Mathematics Offerings for Students with Two Levels of Developmental Need (Figure ES.1)
- Mathematics Outcomes Among Students Enrolled in NMP Foundations at Codevelopment Colleges, fall 2013 through spring 2014 (Table ES.1)

Scott-Clayton, J. (2012, February). ***Do high-stakes placement exams predict college success?*** **(CCRC Working Paper No. 41). New York, NY: Community College Research Center, Teachers College, Columbia University.**

TYPE: Report

KEYWORDS: Math, placement tests, community college

RELEVANT WORKGROUP(S): High School to College Alignment, FCS Mathematics Sequences, FCS to Univ. Alignment

This report examines the predictive validity of a commonly used placement test. The researcher analyzed data on four cohorts of first-time degree-seekers, representing nearly 70,000 students, at a Large Urban Community College System (LUCCS). Employing linear probability (OLS) models (i.e. traditional correlation coefficients and decision-theoretic measures of placement accuracy and error rates), the researcher found placement test scores are more predictive in mathematics than in English; mathematics test scores explain about 13 percent of the variation in first college-level mathematics course grades, while reading/writing scores explain less than two percent of the variation in first college-level English grades. Moreover, placement accuracy rates are higher in mathematics than in English (58 percent compared to 43 percent under a C criterion of success), and severe error rates are lower in mathematics than in English (24 percent compared to 33 percent). Additionally, the researcher found placement exams are more predictive of who is likely to do well in a college-level course than predicting who is likely to fail. The incremental validity of placement exams relative to high school background predictors of success is weak in both mathematics and English, but when high school GPA is accounted, the variation explained increase by about six percentage points in mathematics and less than two percentage points in English. The researcher recommended: (1) Using high school achievement alone reduces severe placement mistakes than using placement exams alone; (2) combining placement test scores, high school achievement, and selected background characteristics (i.e. years since high school graduation and whether a student is from a local high school) could reduce severe placement errors by about 15 percent in each subject and improve college-level success; and, (3) using students' best placement scores or an index of their high school background could "markedly lower the remediation rate without compromising college-level success rates" (p. 38).

Summit on Mathematics Pathways. (2017, March 6-7). ***National strategy for advancing mathematics pathways for student success*****. Indianapolis, IN.**

TYPE: Report

KEYWORD(S): Mathematics pathways, guided pathways

RELEVANT WORKGROUP(S): FCS Mathematics Sequences, FCS to Univ. Alignment

This report highlights a national guided pathways model, by Advancing Mathematics Pathways for Student Success (AMPSS), designed to implement mathematics pathways in at least four states in order to make significant impacts on student success. AMPSS is composed of mathematics professional societies, higher education leadership associations, and national education nonprofits that work directly with institutions and states. The guided pathways model is framed around a mapping system to help students navigate their way to and through higher education. The four key objectives of the mapping system are: (1) Clarify the Path, (2) Help Students Choose and Enter a Pathway, (3) Help Students Stay on the Path; and, (4) Ensure Students are Learning. The report recommended the guided pathways model will: (1) Ensure students are "appropriately placed and enrolled in the rigorous mathematics courses that are needed for their chosen program of study, rather than in mathematics courses such as College Algebra that they may not need" (p. 2); (2) be transferrable and relevant to specific programs of study at all institutions in a state; and, (3) help students to progress through an appropriate college-level mathematics course within one year of matriculation.

Appendix F includes:

- The AMPSS Partnership (i.e. Partners)
- Percentage of Students from Different Groups who Pass a Required College-level Mathematics Course Within Two Years of Matriculation (Figure 1)
- Percentage of Students Taking Remedial Mathematics who Take a Corresponding College-level Course Within Two Years of Matriculation (Figure 2)
- A Common Example of Mathematics Pathways for Certain Programs of Study (Figure 3)
- Many of the States and Institutions Working with AMPSS Partners on Mathematics Pathways Related Initiatives (Figure 4)
- The AMPSS Action Plan for Advancing Mathematics Pathways Across the Nation (Figure 5)
- Phases of Activity for Each State or Region, from the AMPSS Theory of Change (Table 1)
- Roles of AMPSS and AMPSS Partners in Each Phase of a State or Region's Work (Table 2)
- Indicators and Outcomes of Creating or Refining Mathematics Pathways (Table 3)

Wang, X. (2013a). Modeling entrance into STEM fields of study among students beginning at community colleges and four-year institutions. *Research in Higher Education, 54*, 664-692.

TYPE: Peer-Reviewed Article

KEYWORDS: Community college students, STEM education, choice of major, social cognitive career theory, multi-group structural equation modeling (SEM)

RELEVANT WORKGROUPS: High School to College Alignment, FCS Mathematics Sequences, FCS to Univ. Alignment

This peer-reviewed article examines factors believed to shape the decision to pursue science, technology, engineering, and mathematics (STEM) fields. The researchers used nationally representative Educational Longitudinal Study of 2002 (ELS:2002) data of students entering community colleges and four-year institutions. Employing social cognitive career theory and multi-group structural equation modeling (SEM) analysis, the researcher found two main findings. First, the researcher found important heterogeneity in the effects of high school and higher education variables based on where students started their postsecondary education (i.e. community colleges or four-year institutions). Exposure to mathematics and science courses in high school have a strong influence on four-year beginners' STEM interests. However, the impact of mathematics and science courses in high school appears to have a positive yet smaller impact on community college beginners' STEM interests. Secondly, postsecondary academic integration and financial aid have differential effects on STEM entrance, accruing more to four-year beginners and less to community colleges beginners. The researcher recommended high schools should strengthen STEM learning and cultivate STEM interest, and postsecondary institutions should improve the academic integration and financial aid of STEM degree-seeking students.

Appendix G includes:

- Structural Part of Final Multi-group STEM Results, Displaying the Final Multi-group SEM Model with Significant Paths Denoted with Their Corresponding Unstandardized Path Coefficients (Figure 2)

Wang, X. (2013b). Why students choose STEM majors: Motivation, high school learning, and postsecondary context of support. *American Educational Research Journal, 50*(5), 1081-1121.

TYPE: Peer-Reviewed Article

KEYWORDS: Mathematics pathways, STEM participation, college major choice, social cognitive career theory, multiple-group structural equation modeling (SEM)

RELEVANT WORKGROUP(S): High School to College Alignment, FCS Mathematics Sequences, FCS to Univ. Alignment

This peer-reviewed article examines the entrance into science, technology, engineering, and mathematics (STEM) majors by recent high school graduates attending four-year postsecondary institutions. The researcher used nationally representative Educational Longitudinal Study of 2002 (ELS:2002) data. Employing social cognitive career theory and multi-group structural equation modeling (SEM) analysis, the researcher found choosing a STEM major has a direct relationship with (1) intent to major in STEM, (2) high school mathematics achievement, and (3) initial postsecondary experiences, such as academic integration and financial aid. Moreover, influencing the largest impact on choosing a STEM major, intent to major in STEM is "directly affected by 12-grade mathematics achievement, exposure to mathematics and science courses, and mathematics self-efficacy—all three subject to the influence of early achievement in and attitudes toward math" (p. 1081). Additionally, the researcher found heterogeneous effects of mathematics achievement and exposure to mathematics and science across racial groups, indicating positive impacts on STEM intent accruing most to white students and least to underrepresented minority students. The researcher recommended high schools and postsecondary institutions play a vital role in strengthening mathematics achievement and cultivating STEM interest, especially for underrepresented minority students.

Appendix H includes:

- Results of Final Multiple-group Structural Equation Modeling (SEM) Model Based on Race (Figure 3)

Wang, X. (2016). Course-taking patterns of community college students beginning in STEM: Using data mining techniques to reveal viable STEM transfer pathways. *Research in Higher Education, 57*, 544-569.

TYPE: Peer-Reviewed Article

KEYWORDS: Upward transfer, STEM, course-taking, transcript analysis, data mining

RELEVANT WORKGROUP(S): FCS Mathematics Sequences, FCS to Univ. Alignment

This peer-reviewed article examines course-taking patterns of beginning community college students enrolled in one or more non-remedial (i.e. college-level) science, technology, engineering, and mathematics (STEM) courses during their first year of college, and how these patterns are mapped against upward transfer in STEM fields of study. The researcher used nationally representative postsecondary transcript data of 16,960 students at 2620 eligible institutions, over a six-year period, from the Beginning Postsecondary Students Longitudinal Study (BPS: 04/09). Employing data mining analytical techniques (i.e. apriori algorithm, decision list algorithm, and exhaustive CHAID algorithm), the researcher found two main findings. First, the researcher found approximately "4.4% of the study sample transferred into 4-year STEM majors, 26.9% transferred into a 4-year non-STEM major, and 68.7% did not transfer to a 4-year institution" (p. 555). However, disparities existed in STEM and non-STEM transfer outcomes for female students, underrepresented racial minority students, single-parent students, first-generation students, non-traditional age students, and students with low high school GPAs—all groups were less likely to transfer upward into STEM or other areas of study. Secondly, the researcher found students who eventually transferred into four-year STEM fields "proportionately earned more credits within 'likely transferable' STEM and math, but less credits within, other course categories, than students with different transfer outcomes, both during the first year and throughout the 6-year period" (p. 555). Moreover, non-transfer students proportionately earned more credits from "likely terminal" STEM courses. The researcher recommended: (1) The importance of cultivating a more structured and tangible path of course-taking leading to successful STEM transfers; (2) the removal of stereotypes, misconceptions, and hostile campus environments about STEM fields, especially for underrepresented students; and, (3) improved transfer and articulation policies "within and beyond STEM programs across and between 2- and 4-year institutions" (p. 566).

Wang, X., Sun, N., Lee, S. Y., & Wagner, B. (2017). Does active learning contribute to transfer intent among 2-year college students beginning in STEM? *Journal of Higher Education, 88*(4), 593-618.

TYPE: Peer-Reviewed Article

KEYWORDS: Two-year College, active learning, community college, STEM education, transfer intent, transfer self-efficacy

RELEVANT WORKGROUP(S): FCS Mathematics Sequences, FCS to Univ. Alignment

This peer-reviewed article examines whether and how beginning two-year college students' engagement in active learning with science, technology, engineering, and mathematics (STEM) classrooms is related to their intent to transfer to a four-year institution. The researchers used data from a longitudinal survey of 2,995 students enrolled at all public two-year colleges with upward transfer as part of their institutional mission located in a Midwestern state. Employing a path analysis technique, the researchers found the predicted probability of intending to transfer into STEM fields versus no transfer intent "increased by .036 when the active learning score increased by 1 point from its mean" (p. 608). However, the researchers found no significant relationship between active learning and students' intent to transfer into non-STEM majors compared to no transfer intent. Moreover, active learning has an indirect positive effect on transfer intent through its positive influence on transfer self-efficacy. The researchers recommended: (1) Institutional curriculum administrators should have open communication within their departments and conduct assessments to examine whether and how active learning is practiced in classrooms; (2) professional development opportunities should be offered within and across academic departments "as a means of ensuring that all instructors are equipped with the knowledge and skills to cultivate engaging lessons for their students" (p. 612-613); (3) administrators and department leaders should communicate the motivational benefits of active learning at all departmental and faculty gatherings; and, (4) two-year institutions should strategically and intentionally engage their part-time and contingent faculty.

Appendix I includes:

- The Study's Conceptual Framework (Figure 1)

Wang, X., Sun, N., & Wickersham, K. (2017). Turning mathematics remediation into "homeroom:" Contextualization as a motivational environment for community college students in remedial math. *Review of Higher Education, 40*(3), 427-464.

TYPE: Peer-Reviewed Article

KEYWORDS: Contextualization, developmental math, community college

RELEVANT WORKGROUP(S): High School to College Alignment, FCS Mathematics Sequences, FCS to Univ. Alignment

This peer-reviewed article examines a researcher-practitioner partnership aimed at improving the success of underprepared students in mathematics through contextualization at an urban community college serving over 40,000 students. Contextualization is "a diverse family of instructional strategies designed to more seamlessly link the learning of foundational skills and academic or occupational content by focusing teaching and learning squarely on concrete applications in a specific context that is of interest to the student" (p. 428). Employing Mazzeo's (2008) concept of contextualization and mixed method analyses (i.e. classroom observations, unstructured interviews, and quantitative data analysis), the researchers found: (1) When mathematics becomes "real and accessible," students overcome their fear of mathematics often resulting from a perceived mismatch between mathematics problems and their mathematics abilities; (2) through contextualization pedagogy, students begin to understand math's application; (3) through understanding comes appreciation for math's utility, especially regarding career aspirations; (4) through appreciating math, efficacy in mathematics becomes cultivated; and, (5) through the previous four steps, mathematics becomes larger than mathematics "clearly illuminated by the transformation in learning and motivational beliefs as voiced" by the students participating in the study (p. 458). The researchers recommended the five findings should ground the implementation of contextualization in mathematics curricula.

Appendix J includes:

- Contextualization as a Motivational Environment for Remedial Mathematics Students (Figure 1)

Wang, X., Wang, Y., Wickersham, K., Sun, N., & Chan, H. (2017). Mathematics requirement fulfillment and educational success of community college students. *Community College Review, 45*(2), 99-118.

TYPE: Peer-Reviewed Article

KEYWORDS: Mathematics pathways, community college, course-taking, curriculum review, mathematics requirement, transcript analysis

RELEVANT WORKGROUP(S): FCS Mathematics Sequences

This peer-reviewed article examines the timing of college-level mathematics requirement fulfillment in relation to the longer term success of community college students. The researchers used survey data and transcript records of 320 students from an urban community college. Employing a survival analysis technique, the researchers found completing mathematics requirements at earlier (e.g., first semester) or later (e.g., four or fifth semester) stages of college are related to a higher rate of credential completion. Additionally, the researchers found students who engage in (1) active learning, (2) find academics challenging, and (3) feel academically supported are more likely to complete a credential. However, student-faculty interactions are negatively related to credential completion. The researchers recommended: (1) Fulfilling college-level mathematics requirements early produces higher odds of credential completion; and, (2) community colleges can better assist their students by planning educational pathways, programs, and services that prevent students from struggling through necessary mathematics requirements, therefore maximizing their overall success.

Annotated Bibliography Appendices

Appendix A

Crandall, J. R., & Soares, L. (2015). *The architecture of innovation: System-level course re-design in Tennessee*. Washington, DC: American Council on Education.

TYPE: Report

KEYWORDS: Mathematics pathway, re-design, development, gateway, leading change

RELEVANT WORKGROUP(S): FCS Mathematics Sequences

Box 1. TBR Request for Proposal Processes

Developmental Studies Redesign Process
(2006–09 with two-year no-cost extension)

1. Submit proposals: summer 2007
2. Proposals submitted/selected: 27/6
3. Grant award: $40,000
4. Develop pilots: fall 2007
5. Implement pilots: spring 2008
6. Assess pilots: spring 2008–spring 2009

Participating Institutions (subject areas):
Austin Peay State University (algebra)
Chattanooga State Community College (math and algebra)
Cleveland State Community College (math and algebra)
Jackson State Community College (math and algebra)
Northeast State Technical Community College (reading)
Columbia State Community College (reading and writing)

Course Revitalization Redesign Process
(2014–present)

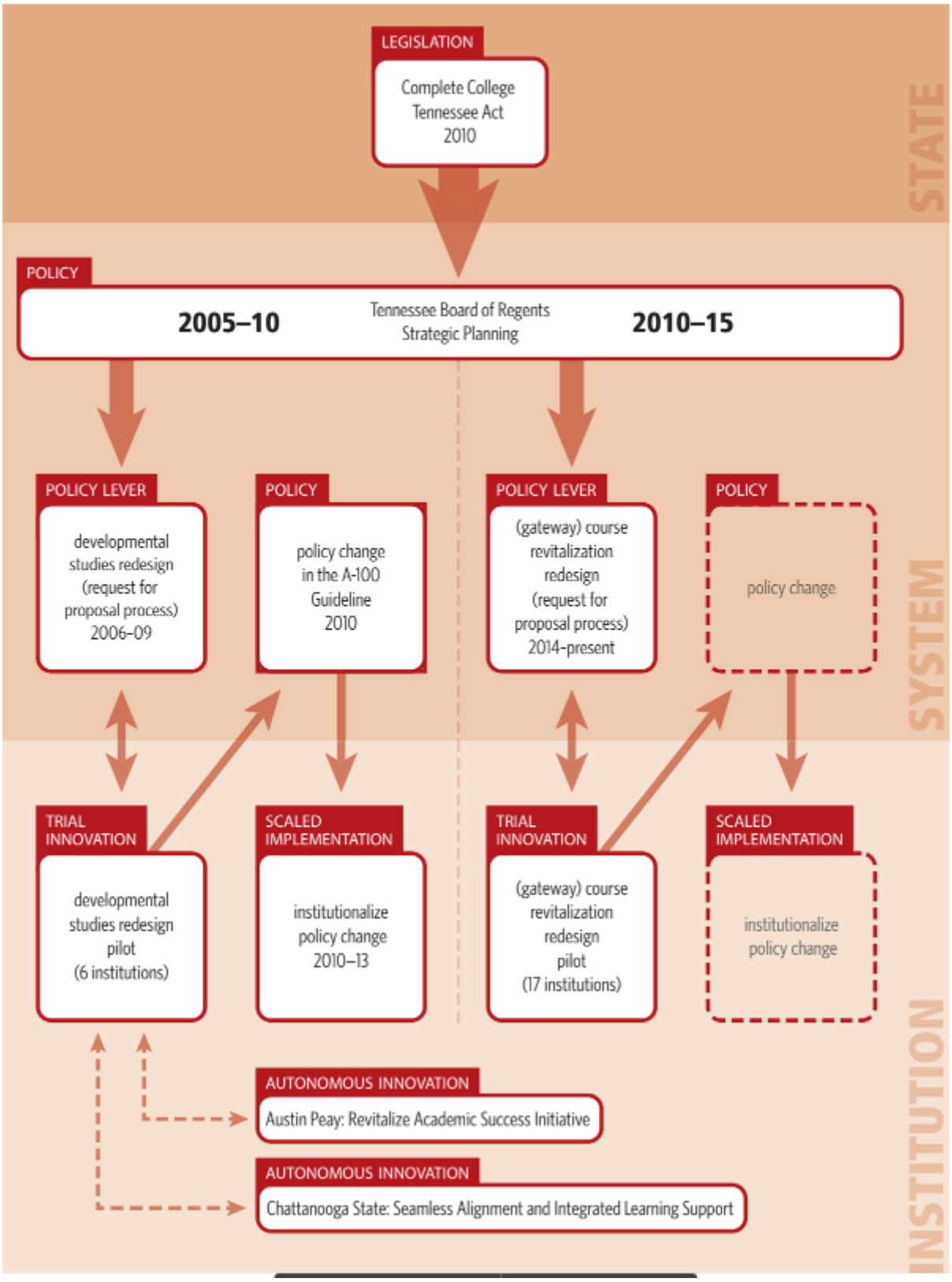
1. Submit proposals: winter 2014
2. Proposals submitted/selected: 120/56
3. Grant award: Two faculty, one course $9,000; three or more faculty, one course $13,500
4. Develop pilots: spring/summer 2014
5. Implement pilots: fall 2014
6. Assess pilots: winter/spring 2015

Participating Institutions (subject areas):
17 institutions; 15 different subject areas (e.g., biology, sociology, speech, health)

Box 2. Kotter's Eight-Stage Change Process

1. **Create a sense of urgency.** Consensus and motivation around change is paramount; 75 percent of management must believe the status quo is problematic and buy into change.
2. **Form a powerful coalition.** Strong leadership alone does not sustain change. An influential team that is representative of an organization's hierarchy must develop and remain over time as it guides the change process.
3. **Create a vision for change.** The guiding coalition contributes to a vision that clarifies the direction an organization should move and connects to values that resonate with stakeholders; visions typically exist in five-year plans.
4. **Communicate the vision.** Communication must be frequent, clear, and credible, and include benefits of targeted change.
5. **Remove obstacles.** Change requires identification and removal of impediments so people are empowered to enact the vision. Impediments typically involve structures or systems not aligned with the vision.
6. **Create short-term wins.** Maintain credibility and momentum of the change process by identifying and celebrating incremental successes based on short- and long-term goals. Short-term wins provide data that minimize the influence of naysayers.
7. **Build on the change.** Maintain focus on urgency and vision that guides development and implementation of new efforts along the hierarchy; use data from short-term wins to inform work moving forward.
8. **Anchor changes in organizational culture.** People need time to internalize the fact that the change has become the way of conducting business; the old model no longer serves a purpose. This requires clearly communicating the validity of the new approach and hiring senior leaders who embody the new direction.

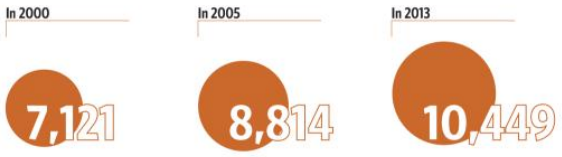
Figure 3. The Architecture of Innovation: System-Level Course Redesign in Tennessee



Austin Peay State University

Austin Peay State University is an urban four-year public, master's-level university. It enrolled 10,449 students in fall 2013 and is one of Tennessee's fastest-growing universities (see Figure 4).

Figure 4. Student Enrollment Headcount (Fall Term)



Data compiled from: Tennessee Higher Education Commission 2015, Tennessee Higher Education Fact Books 2010-2014.

Developmental Studies Redesign. Austin Peay eliminated its two developmental math courses and added enhanced sections to two introductory college-level math and statistics courses based on an iteration of Michigan's Ferris State University's Structured Learning Assistance (SLA) model. The SLA model links a credit-bearing, college-level course to supplemental, supported workshops for students who scored at or below a predetermined score on their ACT, SAT, or COMPASS exam. SLA workshops are facilitated by advanced students who provide individualized and computer-based instruction on course content and prerequisite competencies for students needing developmental math instruction. SLA facilitators also attend introductory courses with students and meet with faculty to discuss students' academic development.

Model:	Structured Learning Assistance (SLA)
Target Course(s):	Elementary Algebra; Intermediate Algebra
Tuition/Fee Structure:	Students pay tuition for the credit-bearing course and a lab fee under $100 for the SLA workshop.
Cost Savings:[7]	Annual cost savings from a) eliminating 52 developmental math sections ($209,248) and b) adding SLA workshops staffed by students.
Student Outcomes:[8]	The pass rate of students who took an enhanced math course was at least 25 percent higher than that of those required to take a developmental math course prior to a college-level math course.

Course Revitalization Redesign

Model:	Co-requisite Model
Target Course(s):	English 1020; Health and Human Performance 1250; Psychology 1010; Sociology 1010
Outcome(s):	To be determined

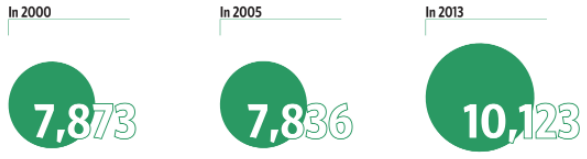
7 Cost savings cover operating costs for personnel over an academic year after completion of the DSR (National Center for Academic Transformation n.d.).

8 Austin Peay's redesign eliminated its developmental education courses, so comparable data on traditional and redesigned courses do not exist; instead, Austin Peay data compare pass rates (grade D or higher with deficiencies removed) of developmental education math students in subsequent college-level math courses before and after redesign.

Chattanooga State Community College

Chattanooga State Community College is an open enrollment institution that offers more than 50 majors of study toward certificates and associate degrees. With 10,123 students in fall 2013 (see Figure 5 for enrollment growth), it serves the tri-state area of Tennessee, north Georgia, and Alabama.

Figure 5. Student Enrollment Headcount (Fall Term)



Data compiled from: Tennessee Higher Education Commission 2015, Tennessee Higher Education Fact Books 2010-2014.

Developmental Studies Redesign. After an unsuccessful attempt to fully implement the initial redesign of its three developmental math courses, Chattanooga State hired a faculty member who led a successful redesign at Tennessee's Cleveland State Community College to assist with a second redesign. The Chattanooga State redesign modularized the courses and implemented the emporium model, which provides on-demand individual assistance to students in a math lab. With this new format, the developmental math program collapsed into two instead of three courses and class size capped at 24. Class met twice a week, once with instructors in a computer lab and again in the math lab. Standardized content and assessment across all sections ensures consistent quality. Modularization supports mastery-based learning and individualized instruction. Streamlining the courses allows students to complete their developmental math course in one or two semesters.

Model:	Emporium Model
Target Course(s):	Basic Math; Elementary Algebra; Intermediate Algebra
Cost Savings:[9]	Annual cost savings from a) reduced cost per student and b) reduced reliance on adjuncts by increasing the number of sections taught by faculty ($165,600).
Student Outcomes:	From 2007 to 2011, withdrawal rates dropped, students exiting developmental math increased, and student GPAs increased.

Course Revitalization Redesign

Model:	Co-requisite Model
Target Course(s):	Biology 2010; English 0810; English 1010; English 1020; Reading 0810; Math 1530; Psychology 1030
Outcome(s):	To be determined

9 Cost savings cover operating costs for personnel over an academic year after completion of the DSR (National Center for Academic Transformation n.d.).

Appendix B

Dana Center. (2016, October). *The case for mathematics pathways*. Austin, TX: Charles A. Dana Center.

TYPE: Report

KEYWORDS: Mathematics pathways

RELEVANT WORKGROUP(S): FCS Mathematics Sequences

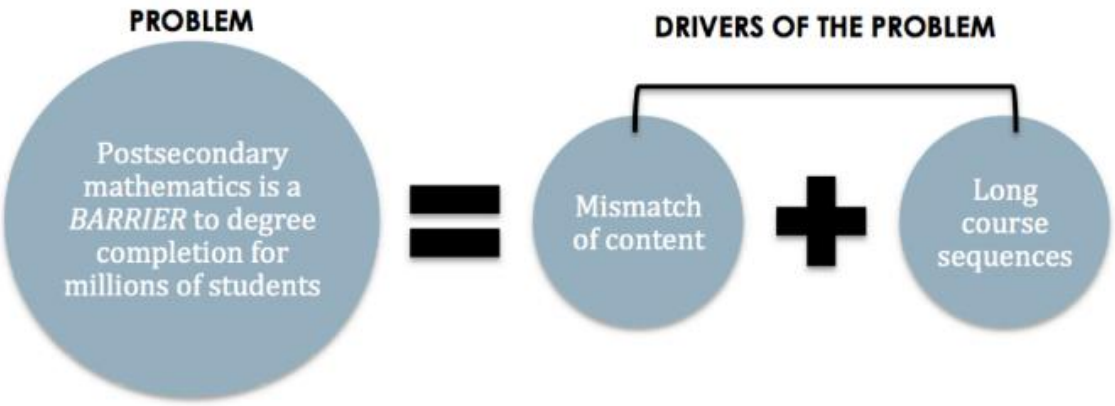


Figure 1. Drivers that create barriers for students.

Appendix C

Martin, R. R. (2017, January/February). Taking student success to scale [TS³]. *Change: The Magazine of Higher Learning, 49*(1), 38-47.

TYPE: Report

KEYWORDS: Mathematics pathways

RELEVANT WORKGROUP(S): FCS Mathematics Sequences

FIGURE 6. TS³ METRICS

Appendix D

Nix, S., Perez-Felkner, L., & Thomas, K. (2015). Perceived mathematical ability under challenge: A longitudinal perspective on sex segregation among STEM degree fields. *Frontiers in Psychology, 6*(530), 1-19.

TYPE: Peer-Reviewed Article

KEYWORDS: Mathematics perceptions, higher education, gender, STEM, pipeline, perceived ability, ability-related beliefs, college major

RELEVANT WORKGROUP(S): High School to College Alignment

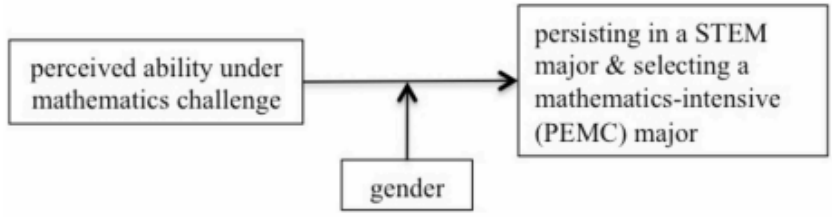


FIGURE 1 | Conceptual model of how gender moderates perceived ability and major choice.

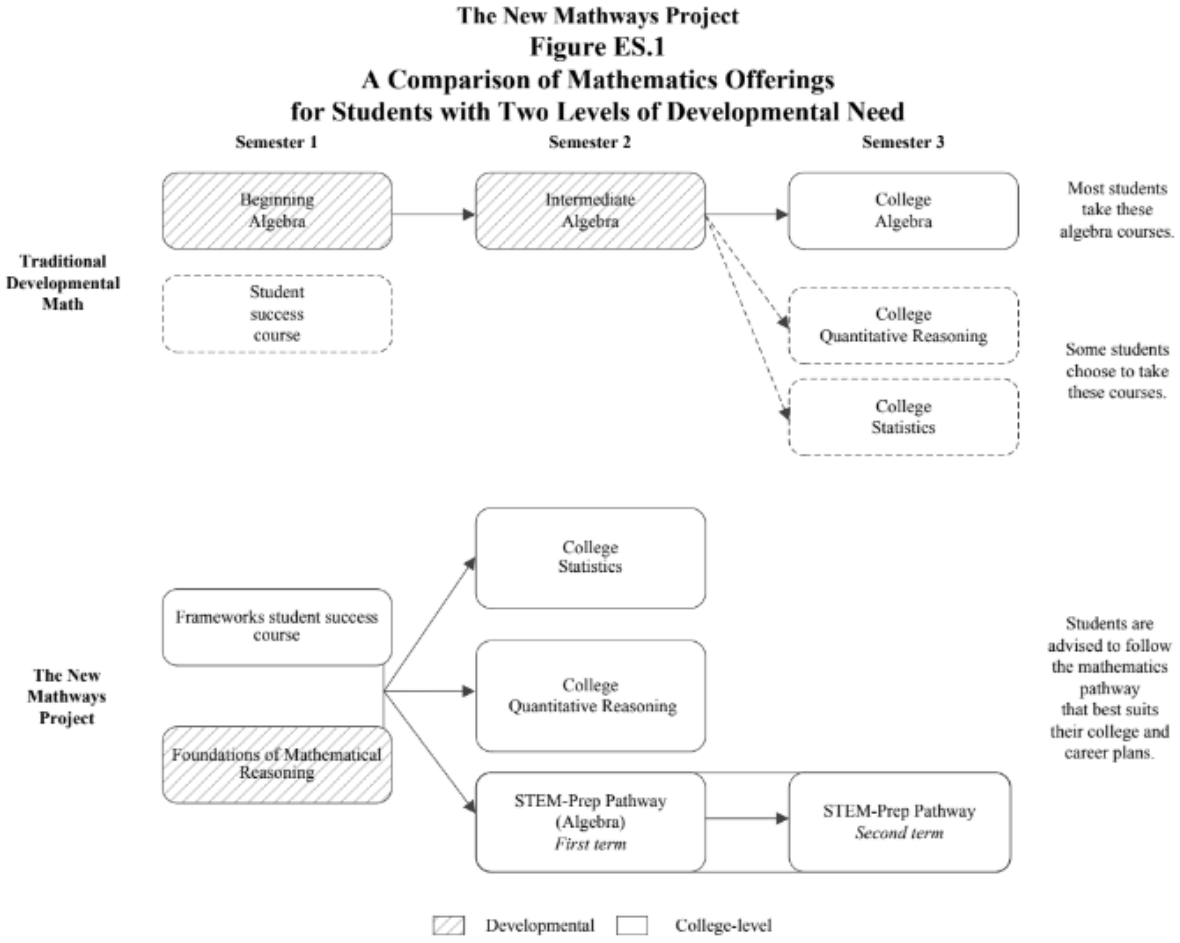
Appendix E

Rutschow, E. Z., & Diamond, J. (2015, April). *Laying the foundations: Early findings from the New Mathways Project*. Oakland, CA: MDRC.

TYPE: Report

KEYWORDS: Mathematics pathways, re-design

RELEVANT WORKGROUP(S): FCS Mathematics Sequences, FCS to Univ. Alignment



The New Mathways Project

Table ES.1

Math Outcomes Among Students Enrolled in NMP Foundations at Codevelopment Colleges, Fall 2013 Through Spring 2014

Outcome	All Colleges Offering Foundations
Number of codevelopment colleges	7
Students enrolled in Foundations in fall 2013	233
Among students enrolled in fall 2013 Foundations, by spring 2014 (%)	
Passed Foundations with "C" or higher	64.8
Enrolled in Statistical Reasoning or other college-level statistics course	45.5
Passed Statistical Reasoning or other college-level statistics course with "C" or higher	30.0

SOURCE: MDRC calculations using college transcript data.

NOTE: Of the eight codevelopment colleges that provided student-level data to MDRC, one did not offer Foundations in fall 2013.

Appendix F

Summit on Mathematics Pathways. (2017, March 6-7). *National strategy for advancing mathematics pathways for student success*. Indianapolis, IN.

TYPE: Report

KEYWORD(S): Mathematics pathways, guided pathways

RELEVANT WORKGROUP(S): FCS Mathematics Sequences, FCS to Univ. Alignment

The AMPSS partnership:

American Association of State Colleges and Universities (AASCU)

Association of Public and Land-grant Universities (APLU)

Carnegie Foundation for the Advancement of Teaching (Carnegie)

Complete College America (CCA)

The Charles A. Dana Center at The University of Texas at Austin (Dana Center)

National Association of System Heads (NASH)

Transforming Post-Secondary Education in Mathematics (TPSE Math)

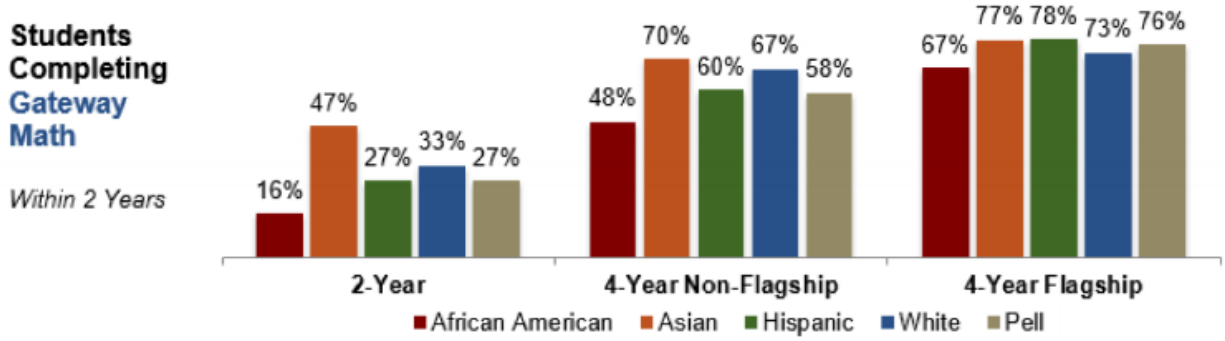


Figure 1: Percentages of students from different groups who pass a required college-level mathematics course within two years of matriculation. N=30 states. *Source: 2016 Complete College America data collection*

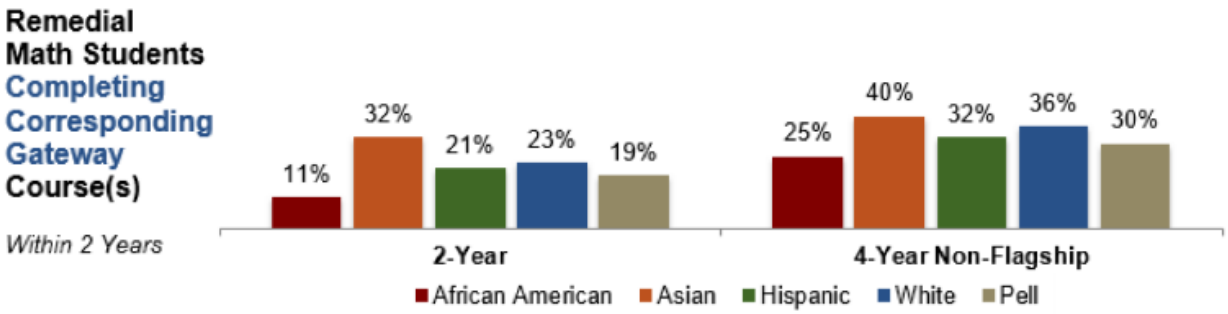


Figure 2: Percentages of students taking remedial mathematics who take a corresponding college-level course within two years of matriculation. N=30 states. *Source: 2016 Complete College America data collection*

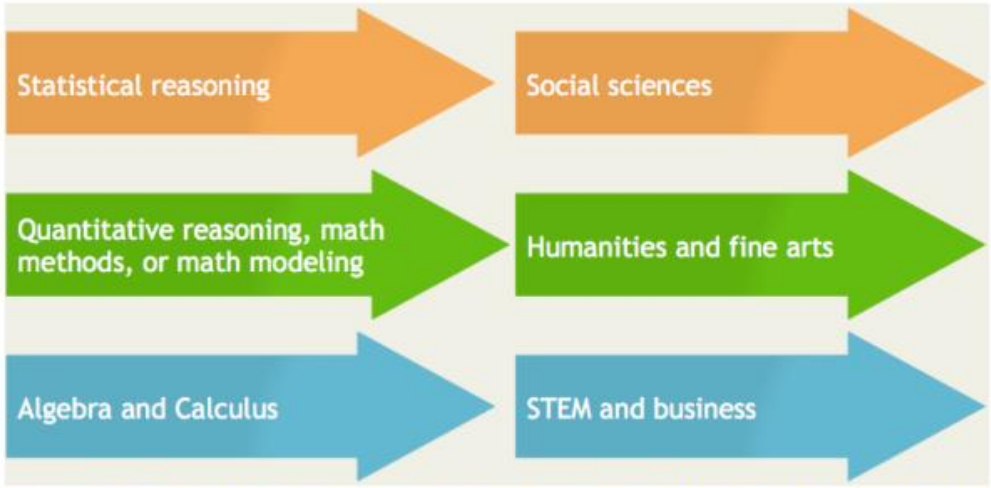


Figure 3: A common example of math pathways for certain programs of study. Other specialized pathways are sometimes designed for education, nursing, business, or other majors.

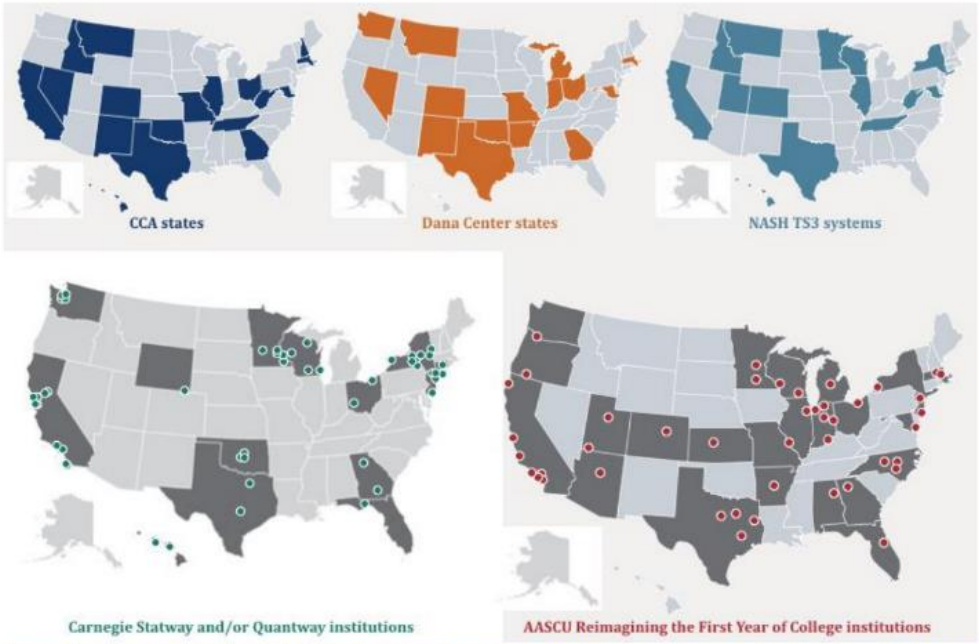


Figure 4: Many of the states and institutions working with AMPSS partners on math pathways related initiatives. *Source: AMPSS partners, 2016.*

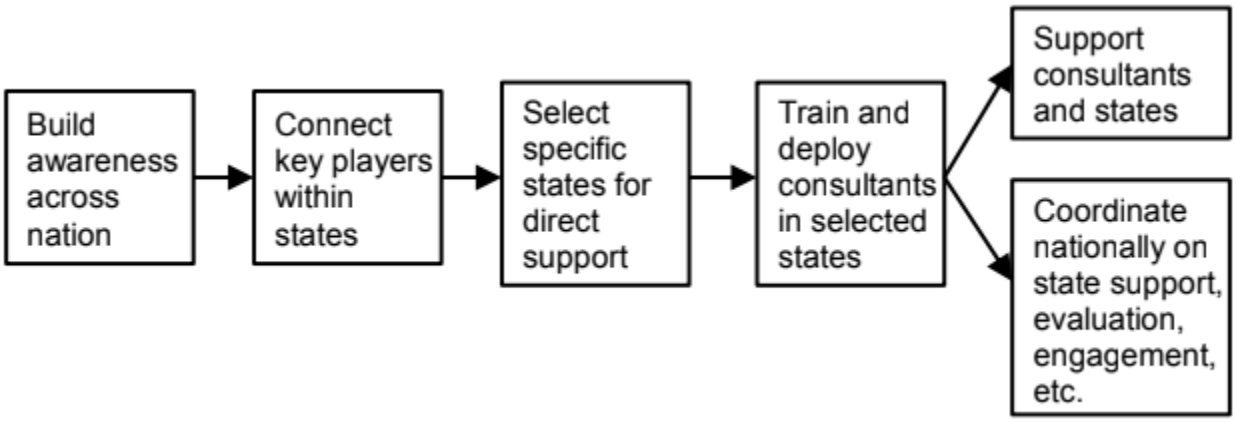


Figure 5: The AMPSS Action Plan for advancing mathematics pathways across the nation.

Table 1: Phases of activity for each state or region, from the AMPSS Theory of Change.

Phase	1. Building awareness	2. Mobilizing	3. Creating enabling conditions	4. Institutional implementation
Activities	Building awareness of math pathways work and its value among key stakeholders, deciding to act	Visioning, identifying goals and barriers, organizing, and planning	Designing pathways, building policy and conceptual infrastructure, minimizing barriers	Implementing pathways and creating the sustaining conditions
Outcomes	Formation of a state math pathways task force	• Published, detailed recommendations from state math pathways task force. • State- or region-wide math pathways task force officially empowered to take action.	• Math pathways and corresponding learning outcomes are determined • Plans made for engaging additional stakeholders, scaling across institutions, evaluating process and impact, and addressing major barriers • Institutions commit to implementation	• Institutions meet criteria for implementation • Evaluation plan is implemented • Students are enrolled in appropriate math pathways as normative practice

Table 2: Roles of AMPSS and AMPSS partners in each phase of a state or region's work.

1. Building awareness	2. Mobilizing	3. Creating enabling conditions	4. Institutional implementation
• Implement a broad national communications plan, including the use of high-level metrics and local results to drive awareness of the issue • Help to mobilize and connect constituents of AMPSS partner organizations (e.g., math faculty, public university leaders, etc.) • Assess all states' readiness and assign each state that is ready for Phase 2 to **a single Lead Collaborator organization from AMPSS** (using a process outlined in the narrative). The Lead Collaborator designs a plan to begin work with that state.	• The AMPSS Lead Collaborator organization for a state coordinates direct, ongoing technical assistance for that state by deploying a trained consultant to each state and providing the AMPSS practitioner's guide. • Provide national and regional networking activities (convenings, online networks, etc.) in coordination with the Lead Collaborators • Continue to engage additional stakeholders • With the Lead Collaborators, monitor state progress and determine which have entered Phase 3 • Collect baseline metrics and continue to mobilize key actors around the existing outcomes	• Lead Collaborator continues to coordinate and provide direct technical support, largely through assigned consultants. • AMPSS partners and other groups provide legitimization; updates and connections with other states; and motivation to remain engaged. • With the Lead Collaborators, monitor state progress and determine which have entered Phase 4 • Share early results to help maintain momentum and create the enabling conditions	• Lead Collaborator continues to coordinate and provide direct technical support for faculty and administrators in implementing, scaling, and evaluating pathways. • Review data regularly to understand impact and make any necessary changes

Table 3: Indicators and outcomes of creating or refining math pathways (from the full framework in Appendix C). Collecting data associated with these outcomes comprises the minimum set of metrics for evaluating progress.

Activities	Outputs or Leading Indicators	Short-term outcomes	Medium-term outcomes	Long-term outcomes
Create or Redefine Pathways	Change in course offerings	Increased Enrollment in new pathways	Increased first year math gateway completion	Increased completion
	Training on pathways for faculty and advisors	Decrease in College Algebra enrollment	Increased fall to fall retention	Increased representation in STEM degrees
			Increase in the % of students enrolled in college algebra who go on to successfully complete a Calculus Sequence	

Appendix G

Wang, X. (2013). Modeling entrance into STEM fields of study among students beginning at community colleges and four-year institutions. *Research in Higher Education, 54*, 664-692.

TYPE: Peer-Reviewed Article

KEYWORDS: Community college students, STEM education, choice of major, social cognitive career theory, multi-group structural equation modeling (SEM)

RELEVANT WORKGROUPS: High School to College Alignment, FCS Mathematics Sequences, FCS to Univ. Alignment

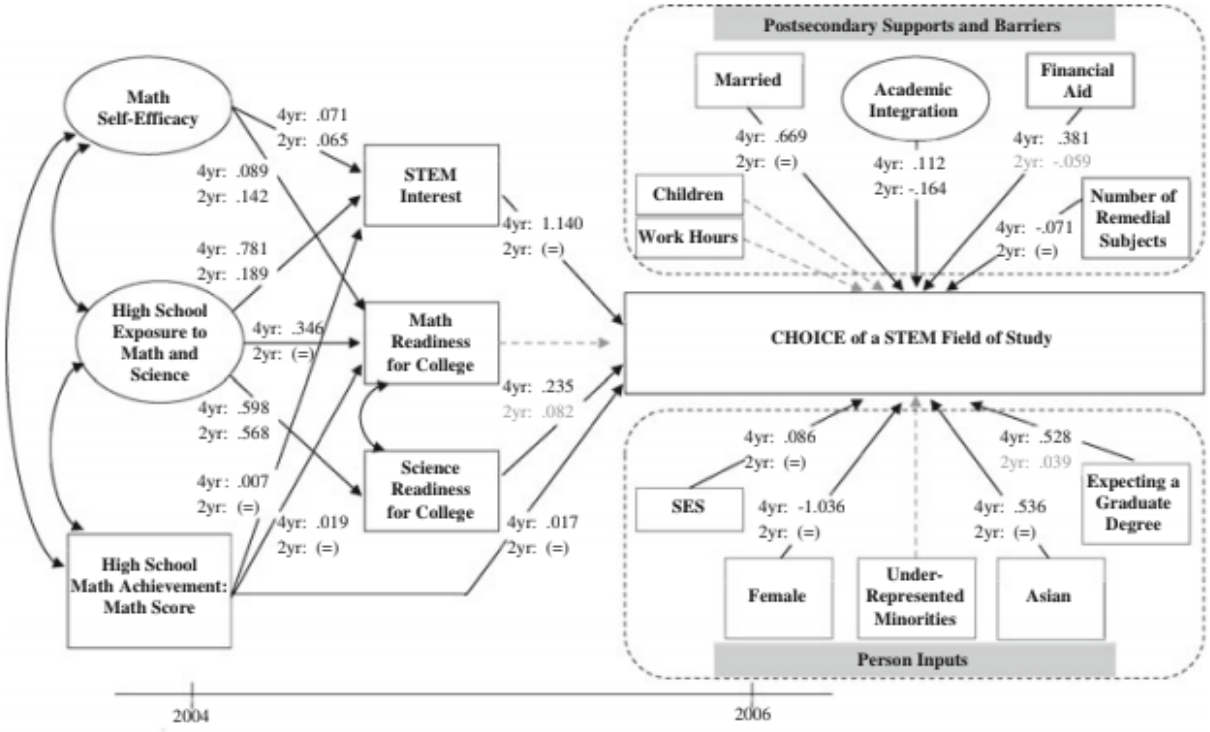


Fig. 2 Structural part of final multi-group SEM results. *4 yr* four-year institution, *2 yr* community college. (=) indicates that the path coefficient is constrained equal across the two student groups. Insignificant paths with $p > .10$ are in *gray color*

reported in Table 7. Figure 2 displays the final multi-group SEM model with significant paths denoted with their corresponding unstandardized path coefficients.

Appendix H

Wang, X. (2013). Why students choose STEM majors: Motivation, high school learning, and postsecondary context of support. *American Educational Research Journal, 50*(5), 1081-1121.

TYPE: Peer-Reviewed Article

KEYWORDS: Mathematics pathways, STEM participation, college major choice, social cognitive career theory, multiple-group structural equation modeling (SEM)

RELEVANT WORKGROUP(S): High School to College Alignment, FCS Mathematics Sequences, FCS to Univ. Alignment

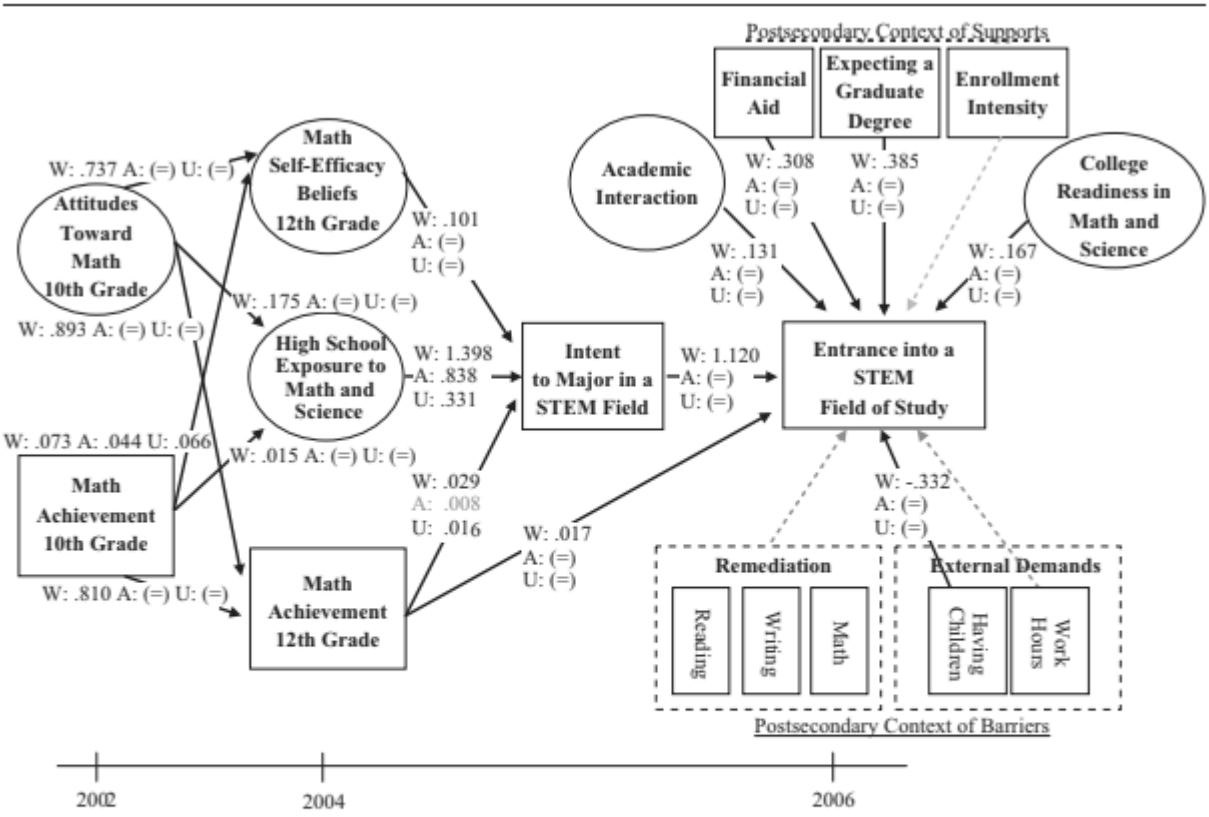


Figure 3. **Results of final multiple-group structural equation modeling (SEM) model based on race.**

Note. W = White; A = Asian; U = underrepresented minorities; (=) = estimate was constrained equal across groups. Insignificant paths are in gray.

Appendix I

Wang, X., Sun, N., Lee, S. Y., & Wagner, B. (2017). Does active learning contribute to transfer intent among 2-year college students beginning in STEM? *Journal of Higher Education, 88*(4), 593-618.

TYPE: Peer-Reviewed Article

KEYWORDS: Two-year College, active learning, community college, STEM education, transfer intent, transfer self-efficacy

RELEVANT WORKGROUP(S): FCS Mathematics Sequences, FCS to Univ. Alignment

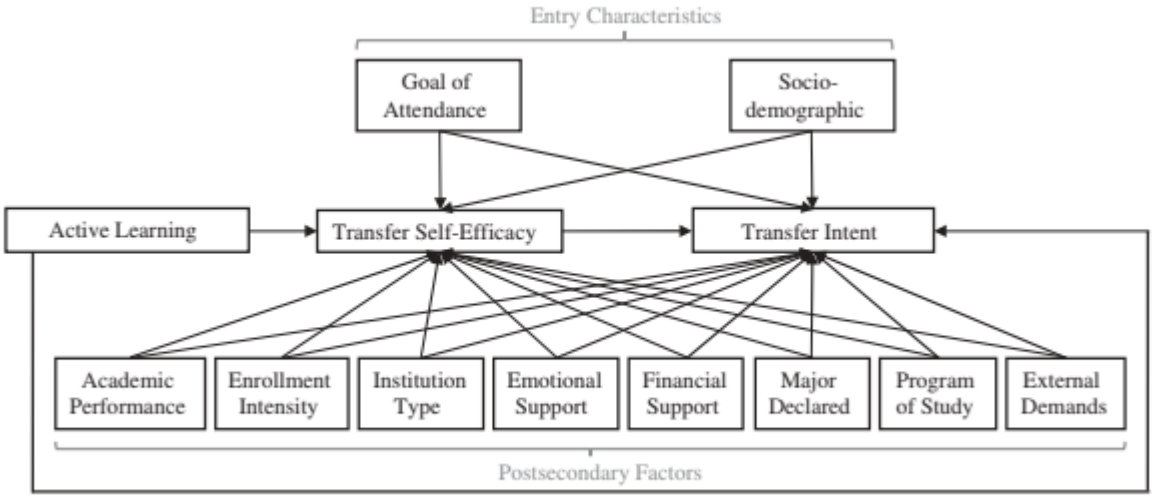


Figure 1. The study's conceptual framework.

Appendix J

Wang, X., Sun, N., & Wickersham, K. (2017). Turning mathematics remediation into "homeroom:" Contextualization as a motivational environment for community college students in remedial math. *Review of Higher Education, 40*(3), 427-464.

TYPE: Peer-Reviewed Article

KEYWORDS: Contextualization, developmental math, community college

RELEVANT WORKGROUP(S): High School to College Alignment, FCS Mathematics Sequences, FCS to Univ. Alignment

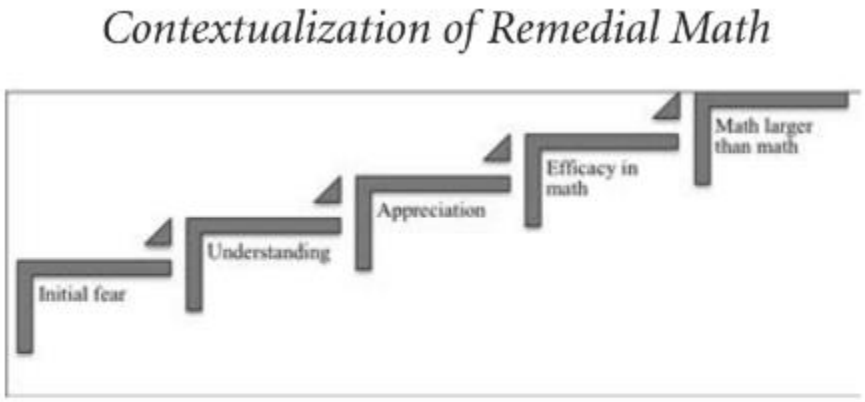


Figure 1. Contextualization as a motivational environment for remedial math students.