A COMPARISON OF DEVELOPMENTAL MATHEMATICS SEQUENCES AT A NORTH CAROLINA COMMUNITY COLLEGE USING A MARKOV CHAIN MODEL

by

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ABSTRACT

MATTHEW ALLAN PEELER. A comparison of developmental mathematics sequences at a North Carolina community college using a Markov chain model. (Under the direction of DR. RICHARD LAMBERT)

This study compares students at a North Carolina community college taking a course-based developmental mathematics sequence to students taking a new, module-based emporium method developmental mathematics sequence using a Markov chain model to compare their effectiveness in progressing students toward completion of their first college-level mathematics course. Preliminary analysis to determine if the data satisfied the Markov property found that students completing previous developmental coursework had comparable pass rates, however, students attempting a course for the second or subsequent time had lower pass rates than students attempting the course for the first time. These lower rates persisted through subsequent courses even after the original course was passed. The Markov chain model was modified to account for these pass rate changes. Students under the new sequence has slightly lower, but comparable, first college-level mathematics course completion rates than those under the old sequence, however, individual course progression rates were higher under the new sequence, suggesting that other factors, such as choice of college-level mathematics course, may be affecting these results. Female and African-American students were more likely to be placed lower under both sequences, and African-American students had lower progression rates under both sequences. Students placed directly into college-level mathematics based on high school GPA and high school courses taken, instead of placement test results, were found to have slightly lower, but comparable, pass rates to

traditionally placed students in college-level mathematics courses, except for those courses requiring the most rigorous mathematics prerequisites.

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TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

Overview

Community colleges have been an increased focus in the national discourse around postsecondary education, largely due to a federal proposal that calls for tuition-free community college under the America's College Promise Proposal (White House Office of the Press Secretary, 2015). However, columnists such as Brooks (2015) note that simply providing tuition does not ensure success, particularly for students requiring developmental education (defined here as classes required to prepare a student for college-level coursework). Indeed, studies into the factors involved in helping to determine the success of students in community college (such as Carlan & Byxbe, 2000 and Scherer & Anson, 2014) show that one of the most important factors is the need for remediation; that is, the need to take developmental courses.

This is particularly important for community colleges since their mission to be "open-door" institutions. Community colleges often admit students who require a significant amount of developmental coursework, particularly developmental mathematics coursework, to get them ready for college-level work. At some community colleges, the percentage of all students required to complete developmental mathematics alone can be as high as over 85% (Klein & Wright, 2009), with African-American and Latino students significantly overrepresented.

Unfortunately, the chances of success for a student needing developmental mathematics coursework is often very low. George (2010) notes that students that require developmental mathematics have a hard time graduating, with nearly 75% of students who were placed into developmental coursework never even completing their developmental coursework. Similarly, Wolfle (2012) found that around 72% of developmental mathematics students never attempted a college-level math course. Given these results, developmental mathematics is clearly a key lever for community college students to successfully graduate.

There have been a variety of initiatives implemented (primarily at the state level) to increase developmental mathematics students' chances to complete college-level mathematics courses. For example, in the Fall 2014 and Spring 2015 semesters, Tennessee piloted a co-requisite model for developmental education, having their developmental students enroll in college-level classes in English writing and introductory statistics, but requiring a co-requisite supplemental learning experience (Tennessee Board of Regents, 2016). This pilot showed large gains in pass rates for the college-level courses. In Fall semester 2015, these efforts were then expanded to include all entry college-level ("gateway") courses in English and mathematics. A full analysis of this co-requisite model will require more longitudinal data, but the initial college-level pass rates still show large gains, although smaller than the pilot study.

On the other hand, Florida recently dispensed with requiring all developmental mathematics courses for traditional (recent high school graduates) students, allowing those students the choice of taking developmental mathematics coursework or enrolling directly into college-level mathematics. The results at one college showed a 25% increase in college-level math or intermediate algebra, while developmental math enrollments dropped by 42% (Smith, 2015). However, pass rates for the college-level courses fell from 55.4% to 46.8%.

In North Carolina, the North Carolina Community College System, which oversees 58 community colleges in the State of North Carolina, redesigned its developmental mathematics sequence in 2012 (North Carolina Community College System, 2012), from a three-course, traditionally taught sequence into a sequence of eight modules and gave each college the ability to choose the structure and instructional methods used to teach these modules (a fourth developmental course, lower than the three which are the focus of this study, was not included in this redesign). The overall goal of this redesign was to support students in need of developmental mathematics to complete their sequence of developmental courses and pass their first college-level mathematics course (called the gateway course).

This new sequence of eight modules covered approximately the same material as the old sequence of three courses, with the material in each one of the old courses being divided into two or three modules. In the description of the new developmental mathematics sequence, the North Carolina Community College System (2011), gave a crosswalk that allowed colleges to determine where students placed into the old three courses sequence would be placed in the new developmental mathematics sequence:

- The old developmental math course MAT 060 was covered by the material in Modules 1-3, so a student placed into MAT 060 would be placed into Module 1.

- The old developmental math course MAT 070 was covered by the material in Modules 4-6 (minus a few sections at the end of Module 6 that was covered in MAT 080), so a student placed in MAT 070 would start in Module 4.
- The old developmental math course MAT 080 was covered by Modules 7 and 8 (plus the few sections in Module 6 not in MAT 070). To ensure that all appropriate sections were covered, a student placed in MAT 080 would start in Module 6.

While there have been small local efforts to determine the effectiveness of this new development mathematics sequence, and larger studies are underway, the overall effectiveness of this redesign on students at all levels of the sequence has not been adequately tested, in part due to the complexity of adequately comparing the results of the old developmental mathematics sequence to the new sequence.

Also, in an effort to reduce the number of students being placed in developmental coursework, the North Carolina Community College System added a new criterion for developmental course placement. First drafted in 2011 and called the Multiple Measures for Placement (North Carolina Community College System, 2011), or Multiple Measures, the new policy allowed for alternate methods of course placement in English and mathematics other than a diagnostic placement test (either Accuplacer or COMPASS), which was, for an overwhelming majority of students, the only method of placement.

The new Multiple Measures used the following hierarchy of measures (North Carolina Community College System, 2011):

1. A student who had a transcript from a high school which showed that the student had an unweighted GPA of 2.6 or higher and had completed four years of high school mathematics with one year above the level of Algebra II would be placed directly into college-level mathematics coursework.
2. A student who had a score of 22 or higher on the math portion of the ACT, or a score of 500 or higher on the math portion of the SAT, would also be placed directly into college-level mathematics coursework.
3. A student who had previous college-level credit in mathematics at another college would be placed directly into college-level mathematics coursework.
4. If a student does not meet any of the requirements above, then the college will administer a diagnostic placement test to determine the student's placement into developmental or college-level mathematics coursework.

While Multiple Measures was due to be implemented fully in 2015, some colleges implemented the new criteria early, with mixed results in terms of the gateway course completion rates of these newly placed students (see Center for Community College Student Engagement, 2016, for an example of Multiple Measures implementation and an analysis of pass rates by student placement at one community college in North Carolina).

All of these issues require a more complete analysis of both the old and the new developmental mathematics sequences and their effects on student progression. To properly address the important questions around these sequences, a new modeling technique, one using a mathematical model called Markov chains, will be used to properly analyze all portions of both of the developmental mathematics sequences, and help to answer more specific questions regarding student progression through those sequences.

This study will specifically seek to address the following research questions:

1. Do students progress through their developmental mathematics sequence and through their chosen gateway mathematics course at a better rate in the new developmental mathematics sequence than in the old developmental mathematics sequence, given their initial placement?
2. Do different student demographic variables (gender and race/ethnicity) have an effect on the progression rate through these two developmental mathematics sequences?
3. Are their particular courses or modules in these two developmental mathematics sequences that have higher or lower rates of progression (pass or completion rates)?
4. Do students placed directly into the gateway mathematics courses, particularly by the Multiple Measures method used by the North Carolina Community College System, complete the gateway course at similar rates than those that are placed into the gateway course by other methods (either by placement test or by completing developmental coursework)?
5. Does the crediting of completed modules (under the new developmental mathematics sequence) in a module shell course that the student failed (here called *partial credit*) have an effect on student progression, as opposed to the old developmental mathematics sequence, which had no option for partial credit?

Delimitations

The study will be restricted to students who were enrolled in a developmental mathematics or gateway mathematics course in one medium-sized suburban community college in North Carolina from Fall Semester 2007 to Summer Semester 2015, which is the main timeframe of the study.

At the college used in the study, the developmental redesign was implemented in Fall Semester 2012, so the study's timeframe covers five years of data of the former, traditionally taught, developmental mathematics course sequence (Fall Semester 2007 to Summer Semester 2012), and three years of data of the new emporium shells developmental mathematics sequence (Fall 2012 to Summer 2015).

Additional data will be collected before the main timeframe of the study, and also an additional year after (Fall Semester 2015 to Summer Semester 2016) the main timeframe of the study. The data before the main timeframe will be used for student placement and transfer course information and also for assumption checks (specifically the Markov property), while the added year at the end of the study will allow for students still within the developmental mathematics sequence to have the opportunity to complete their developmental mathematics sequence and gateway curriculum mathematics course.

While the demographic characteristics of community college students in general, and community college students in North Carolina in particular, are the primary focus of this study, exact generalizations may be limited to those community colleges using the emporium shells sequence, and also by factors listed in the Limitations section below.

Limitations

When developing the developmental mathematics redesign, the North Carolina Community College System mandated the modular structure of the redesign, but allowed its 58 member colleges some flexibility in the manner in which they structured and taught the courses. Colleges were allowed to structure the courses as individual modules (taught in a four- or five-week timespan), or as a module shell, a group of one to three modules taught together over the course of a half (8 weeks) or a full (16 week) semester. Colleges were also allowed to choose the instructional method used, either taught by the traditional method, taught on-line, taught by the emporium method, or some combination of all three.

The college where this study is to take place chose to use the module shell structure for the new developmental mathematics sequence, and chose to teach all of the courses by the emporium method, thus limiting the study to this specific combination of structure and instruction method.

Further, during the timeframe of the study, there were some changes made to the methods that were used to place students into developmental mathematics courses. The college changed from using two different placement tests (ASSET and Compass) for entering college students to using just one test, the Compass test. Other placement tests that were used by the college (such as the SAT and ACT) remained unchanged during the timeframe of the study. The college’s scores and placements for these tests conform to standard practice at other community colleges in the state. A further, and more complete, change in placement testing was implemented in Fall Semester of 2015, with the creation of the North Carolina Community College System Diagnostic and Placement Test (NC

DAP). This new test has some dramatic effects in how students are placed in developmental mathematics modules, making its implementation an appropriate end to the timeframe of the study.

A further complication to the study was the implementation of Multiple Measures (described in the introduction above). Multiple Measures was required to be implemented by all 58 community colleges by Fall Semester 2015; however, colleges could choose to use the new measures earlier. The site for this study implemented Multiple Measures in Fall Semester of 2013. The success of students placed into gateway mathematics courses by Multiple Measures is a subject of much interest to the North Carolina Community College System, and is an added topic of interest of this study.

Finally, the North Carolina Community College System as a whole, and the study college in particular, had a large increase in enrollment over the academic years 2007-2010 due to a nation-wide recession. In the past, many of the students who come to community colleges during a recession may have different characteristics than the typical community college student. These students tend to be more non-traditional in age, be less familiar with how college works, and may need more developmental coursework, all of which could affect their progression in a possible developmental mathematics sequence.

Assumptions

The study assumes that the students do not vary widely in any unmeasured variables over the timeframe of the study, and that the placement tests and procedures used by the college were implemented fairly, and are valid and reliable in placing students in mathematics courses.

While there have been some minor alterations and course number changes in some of the gateway courses during the timeframe of the study, this study assumes that there have been no major structural changes (such as a complete overhaul of the material covered) in both the developmental and gateway courses over the timeframe of the study (outside of the changes made in the developmental mathematics redesign). The study also assumes that there were no significant differences in the goals of the courses and programs, in the efficacy of different faculty members instructing the course, and in the focus of the faculty that taught the courses, during the timeframe of the study.

Definitions

This study will be using terms both from the field of education (terms used and defined as given in North Carolina Community College System, 2011) and from the field of probability theory (specifically Markov chains), and will be presented in a fashion that is conducive to being read by a non-expert in these fields. In particular, the definitions for the terms used in Markov chains are designed to be understood by those outside of the field of probability theory, and are, therefore, not meant to be the exact, precise definitions used in the field of mathematics. For a full definition of the mathematical terms used in the study, refer to Norris (1997).

Education Terms

Developmental Course: While some authors make distinctions between developmental and remedial courses, for the purposes of this study, the term *developmental courses* will be used in accordance with the practice used by the North Carolina Community College System, which is the practice utilized by the college in the study. In this case, a *developmental course* is a stand-alone college course (not linked or connected to any other course) that is primarily designed to give students the preparation necessary to complete a college-level course.

Developmental Course Sequence: A sequence of developmental courses that prepare a student to complete a college-level course, along with the gateway college-level course for which the sequence is designed. These courses are designed to be taken in sequence (i.e. the first course in the sequence must be passed before taking the second course in sequence, etc.). Depending on the placement of a student and their prospective major program of study, they are assigned a developmental course sequence and may be placed in any course in that sequence.

Gateway Course: The first college-level mathematics course that the student takes in their course of study, and the course viewed as the final course in a developmental mathematics sequence. These courses are often called *gateway* (or *gatekeeper*) courses due to their key placement in helping to determine if a student will complete certain programs.

Module: A short series of lectures on a topic, usually designed to be shorter than a full-length course, which, for community colleges in the North Carolina Community College System, is 16 weeks. The new developmental mathematics sequence redesign changed a 3 course sequence into a sequence of 8 modules.

Module shell: A group of 1 to 3 modules, meant to cover either a half (8 weeks) or a whole (16 weeks) semester's work in the new developmental mathematics sequence. Students select how many modules they want to cover in the shell, which determine the amount of time the student will be in class (1 module = 2 hours per week for 8 weeks, 2 modules = 2 hours per week for 16 weeks, 3 modules = 3 hours per week for 16 weeks).

To pass the course, the student must complete all of the coursework for all of the modules selected. Colleges could select to use individual courses for each module or use modules shells. The college in this study used module shells.

Partial credit: In the module shell structure, a student who does not complete all of the modules in their shell course gets a failing grade (“R”, for developmental repeat) for the course. However, if the student does complete all of the material for a module or modules, they still receive credit for those module(s) completed, and will then, in future semesters, start their next developmental mathematics course at the next uncompleted module. For this study, *partial credit* refers specifically to the practice of crediting students for completed modules in a module shell course in which they received a failing grade.

For example, if a student signs up for 3 modules (Modules 1-3) and only completes Modules 1 and 2 and part of Module 3, they receive a failing grade (an “R”) for the course, but they are given credit for Modules 1 and 2 as *partial credit*. The student would not receive any credit for the partially completed Module 3, since only fully completed modules can be credited to the student. Therefore, when the student enrolls in a developmental mathematics course, they would start at the next uncompleted module (in this case, at the beginning of Module 3).

Developmental Math Redesign Crosswalk: A crosswalk designed to convert the old 3 course developmental math sequence (MAT 060, 070, 080) into the new 8 module sequence (Modules 1-8). This crosswalk states that Modules 1-3 correspond to MAT 060, modules 4-5 correspond to MAT 070, and modules 6-8 correspond to MAT 080.

Traditional method: Used to refer to the traditional, classroom-based lecture style instruction method. One of the three instructional methods allowed for the new developmental mathematics sequence.

Internet (online) method: Used to refer to instruction given online, either synchronously or asynchronously. One of the three instructional methods allowed for the new developmental mathematics sequence.

Emporium method: An instructional method where students are instructed in a computer lab by video lectures and problem sets given on the computer, with instructor(s) present to answer questions, administer tests and quizzes, and give individualized instruction if needed. While all students in an emporium classroom are developmental mathematics students, they may not all be on the same module at the same time, and can therefore proceed at their own pace. One of the three instructional methods allowed for the new developmental mathematics sequence, and the one used by the college in the study.

Markov Chain Terms

State (stage): A specific state or position. For this study, the *state* is the specific course or module that a student is taking at the start of the semester, plus some other added states (such as “Withdrew from College” or “Passed Curriculum Math”).

State-space: A list of all possible states or positions. The *state-space* for this study is all of the course in the developmental mathematics sequence, along with the added states above.

Discrete time: Used to refer to a process where time is measured in specific, usually whole number increments (1, 2, 3…), as opposed to measuring time in fractional units.

This study uses semesters as the time unit, and only moves students from state to state at the end of the semester, so it uses *discrete time*.

Transition: The act of moving from one state to another within one unit of discrete time. For this study, this is the movement of a student from one course in the developmental sequence to another (by passing their present course or modules). A student who does not move to a new state is transitioned back to the state they were in originally.

Transition probability: The probability of transitioning from one state to another state in one unit of time. This corresponds with the pass rates or completion rates of the course or module a student is in. As noted above, a student can transition back to the state they were in (by failing to pass a course or module), which also has an associated probability. The total of all *transition probabilities* for each state to all states in the state-space (including itself) must equal 1.

Transition matrix: A matrix (rectangular set of numbers) which contains all of the transition probabilities for all states. As noted above, each row of the matrix, which corresponds to all of the transition probabilities for a given state, must total up to 1.

Absorbing state: A state where the transition probability to itself is equal to 1, making all other transition probabilities equal to 0. Therefore, once a student enters this state, they stay in that state forever. The added states of “Withdrew from College”, “Passed Curriculum Math”, “Graduated Without Curriculum Math”, and “Still Enrolled” will be designed as absorbing states, and are meant to be the final results for those students.

Markov property: A key property of Markov chains, the Markov property states that the transition probabilities for an object in a state cannot be dependent on any past states except for the current state. In short, this says that the chance of a student transitioning from one developmental course or module cannot be affected by any previous courses or modules (i.e. if a student is in MAT 070, their chances of passing are the same whether they were placed directly in MAT 070 or came to MAT 070 by passing the previous course, MAT 060). This means that the model is "memoryless", that is, it does not remember a student's past.

(Discrete-time) Markov chain: A *(discrete-time) Markov chain* is a state-space with a transition matrix measured in discrete time units where every transition probability in the transition matrix has the Markov property.

For this study, the *Markov chain* consists of all of the developmental and gateway courses, along with the extra absorbing states "Withdrew from College", "Passed Curriculum Math", "Graduated Without Curriculum Math", and "Still Enrolled" which is the initial state-space of the chain. There is also a set of pass rates or completion rates which serves as the transition probabilities in the transition matrix, and the study will proceed under the assumption (once it has been checked) that the Markov property holds for all transition probabilities.

Method of Analysis

To perform an accurate analysis of the old and new developmental mathematics sequences, given all of the different points in these sequences that students can be placed, a different approach is needed than the standard cohort model, where the students analyzed all started at the same time and were placed in the same course. After some consideration, the Markov chain model was chosen as the model used for this study, in part because it has several advantages, unique to this specific situation, over the standard cohort model:

1. The Markov chain model allows for the flexibility of comparing students who place at different points in the developmental mathematics sequence (or into the gateway course directly), and allows for their progress to be tracked through their coursework via the transition probabilities in the transition matrix.
2. The Markov chain model allows for students to have transition probabilities from any state in the chain to any other state in the chain, which makes it able to account for students completing more than one module in a semester, which is one of the asserted advantages of the new developmental mathematics sequence.
3. The Markov chain model also allows for multiple branches to the gateway mathematics course, which is important since certain programs have specific mathematic course requirements that do not have the same mathematics pre-requisites, meaning that students in those programs "leave" the developmental mathematics sequence at different points, which can bias the results of the standard cohort model.
4. Finally, the Markov chain model allows for the analysis of "failure points" in the sequence, that is, the ability to determine where in the chain of developmental courses or modules that students who did not complete had the most difficulty (i.e. where the returning transition probability is high and/or the progression to higher states is low). This will allow policymakers to address issues within those specific courses, which would

be more focused and cost-effective than trying to implement changes over the entire developmental mathematics sequence as a whole.

This study utilized the Markov chain model to analyze both developmental mathematics sequences. First, both models were checked for the Markov property assumption. If either model failed to hold the Markov property (due to numerous states having significantly different pass/completion rates for students placed directly into the state versus those moving into the state from a previous state, or staying in that state multiple times), an adjustment to the Markov chain would be implemented, which would allow the Markov property to be satisfied.

For example, if it was found that MAT 070 students have different transition probabilities if they are taking MAT 070 for the first time or have taken the course previously, the Markov chain could be augmented by adding a “return” (-R) state to the chain (i.e. MAT 070 would then have two states, MAT 070 and MAT 070-R, for students who are taking MAT 070 for the first time and those who took MAT 070 previously and failed, respectively). Students failing MAT 070 for the first time would be transitioned from MAT 070 to MAT 070-R. The new chain would then satisfy the Markov property for the new MAT 070 states.

The two Markov chains were then compared in terms of their transitions to gateway courses and the absorbing states, which would be the equivalent of most previous studies. Standard demographic variables were then considered as possibly affecting the transition probabilities, which would, again, be the equivalent of previous studies.

Further analysis of the chains then focused on looking at states where the self-transition probability (the chance of failure) was particularly high, or the mean number of modules passed was lower, which would denote areas where the sequence could be improved.

The completion rates of students placed directly into the gateway course (particularly by Multiple Measures) was also compared to students at various points in the sequence, which would help determine if Multiple Measures is an accurate placement strategy.

Finally, an analysis of the effect of partial credit was attempted by "reducing" the new developmental mathematics sequence Markov chain to the parameters of the old developmental mathematics sequence. Using the crosswalk of coursework mentioned above, this model started by restricting the group of students analyzed to the following:

1. Students in module 1 taking three modules in a semester (the equivalent of the old MAT 060).
2. Students in module 4 taking three modules in a semester (the equivalent of the old MAT 070). Here, students taking three modules in a semester are used to more accurately match the amount of time spent in the classroom.
3. Students in module 6 taking three modules in a semester (the equivalent of the old MAT 080).

This specific cohort of students was then analyzed using the Markov chain model, comparing the transition of the old developmental courses directly to their comparable group in the new developmental mathematics sequence, and by comparing the mean number of modules completed by both systems (counting completions of the old developmental course MAT 060 as passing 3 modules, MAT 070 as passing 2 modules, and MAT 080 as passing 3 modules). The first comparison was the equivalent of comparing the two systems without partial credit, while the second comparison compared the two systems counting the partial credit modules earned in the new developmental mathematics sequence.

Chapter Organization

Chapter 1 contains an introduction to the study, along with the appropriate terms and limitation/delimitations stated here.

Chapter 2 covers the literature review, focusing on the topics of developmental education, specifically developmental math education at community colleges, its relevance to completion, styles of educational instruction (specifically the emporium method of instruction), and the uses of the Markov chain model in education.

Chapter 3 discusses the site selection, site context, population studied, and the details of the Markov chain model (described briefly here).

Chapter 4 details the analysis, starting with the demographic breakdown of the sample, the checking of the Markov property assumptions, and comparison of the two models, covering the material detailed above.

Chapter 5 discusses the conclusions, states what generalizations can be made from the study, suggests modifications to the study for the different options that the North Carolina Community College System allowed for the new developmental mathematics sequence, and offers some areas for further research on this topic.

CHAPTER 2: LITERATURE REVIEW

Introduction

This chapter provides a brief overview of the relevant literature about developmental mathematics education at community colleges. First, an overview of the recent efforts to encourage college completion, with a particular focus on community college students, is described, followed by data and research regarding developmental education. A discussion of a traditional developmental mathematics education sequence ensues, followed by a description of, and some research and history on, typical placement testing procedures. Next, there is a review of the results of studies on developmental students and their rates of progression through their developmental courses, and their retention and completion rates, along with a discussion about the possible misalignment of developmental mathematics courses to their programs of study. Concerns about these research studies, along with a discussion of possible selection bias, are also described. A brief discussion of the effect of developmental coursework on a student's self-efficacy is also discussed. Then, some new approaches to developmental education are described, along with any relevant literature, with a particular emphasis on using high school GPA to inform the placement process (often called Multiple Measures) and the emporium method instructional model. These two new approaches are used in the North Carolina Community College System's redesign of developmental mathematics (North Carolina Community College System, 2012), which is then described. Finally, there is a brief discussion of the recent literature on the use of Markov chains (the model used in this study) to study student progression.

Community Colleges and the Completion Agenda

College completion has been a topic of much concern to people in higher education and to the general public. Studies have shown that America is falling behind the rest of the world in the production of college graduates (National Center for Public Policy and Higher Education, 2006; Tierney, 2006). The United States is ranked twelfth in the percentage of the population aged 25 to 34 that have attained a postsecondary education, but fifth for the population aged 25 to 64, suggesting that our postsecondary achievement rate has fallen in comparison to other countries (Organization for Economic Co-operation and Development, 2013). In fact, college completion rates for both two-year and four-year colleges have not changed since the 1990s (Mortenson, 2009; Radford, Berkner, Wheeless, & Shepherd, 2010).

In response to these facts, numerous agencies have put forth challenges to encourage college completion. The American Association of Community Colleges' 21st-Century Commission on the Future of Community Colleges has challenged colleges to double the rate of students who complete developmental programs and succeed in their college-level gatekeeper course by 2020 (American Association of Community Colleges, 2015). The Lumina Foundation has set a goal that 60% of Americans will hold a college degree, certificate, or other high-quality postsecondary credential by 2025 (Lumina Foundation, 2015). The Bill and Melinda Gates Foundation has also urged colleges to dramatically increase the number of people with labor-market valued postsecondary degrees (Bill & Melinda Gates Foundation, n.d.). The White House has also set a goal:

By 2020, America will have the highest percentage of college graduates in the world (White House, n.d.). The rationale behind these efforts is quite clear, given the advantages gained by earning a postsecondary credential. Earning a college degree not only helps students get better and higher-paying jobs, it is also associated with better health and more civic participation (Baum & Ma, 2007; Dowd, et al., 2006).

These concerns are of particular importance to community colleges, given their mission, the types of students they serve and the range of programs and services they provide. Historically, the massive expansion of higher education in the 1960s brought about the construction of hundreds of community colleges (McGrath & Spear, 1987), providing access to higher education to a large student population (Crews & Aragon, 2007). These community colleges have multiple functions that they have to provide simultaneously (Ewell, 2011). Community colleges often serve students who have other obligations (work, family, etc.) than solely attending college. Community colleges allow underprepared students access to higher education, and give them the opportunity to acquire the academic skills needed for college-level classes through developmental coursework (Cohen & Brawer, 2008; Ewell, 2011; Jenkins & Boswell, 2002). For many minority and economically disadvantaged students, community colleges represent the only access to higher education (Cohen, 1987).

Increasingly, community colleges serve a larger percentage of postsecondary students. 44% of all undergraduates in the United States in 2005 were in community colleges, and that percentage is trending upward (Lutzer, Rodi, Kirkman, & Maxwell, 2007).

Community colleges also serve as a “low cost” form of higher education. Community colleges enroll 35% of postsecondary students at a cost of $38 billion annually (Provasnik & Planty, 2008). In 2007-2008, community colleges received only 27% of the total funding (federal, state, and local revenues) for public, degree-granting institutions, but served 43% of the total number of undergraduate students (Mullin, 2010).

However, numerous studies have shown that, despite high expectations from students at community colleges, retention and completion rates of those students have not been good. According to data from the 2014 Survey of Entering Student Engagement (SENSE), 61% of entering community college students believe that they will complete a degree in two years or less, and 76% of them believe that they are on track to reach their academic goals within their expected time frame. However, only 39% will earn a degree or certificate within six years (Center for Community College Student Engagement, 2016). Nearly 90% of community college students that enroll for credit state that they want to earn a credential or transfer to complete a degree at a four-year school (Hoachlander, Sikora, & Horn, 2003). Another study (Horn & Skomsvold, 2011) found that nearly 80% of entering community college students indicate that they want to earn at least a bachelor’s degree, but, after six years, only 15% have actually earned that degree (Shapiro, et. al., 2012).

Other studies found that only around 20% of community college students who intend to transfer to a four-year institution will do so within three years (Doyle, 2006; Laanan, 1996, 2003). Bailey, Calcagno, Jenkins, Kienzl, and Leinbach (2005) found that only 16% of first-time, full-time community college students that intended to transfer to a four-year institution did so within three years, and with another 22% earning a postsecondary degree or certificate. Tinto (2012) found that less than one-third of community college students earn an associate’s degree or certificate at their first institution within six years. Although some students will take longer to earn their degrees and other students will transfer to another institution; as a whole, only at most two out of every five community college students will eventually earn a degree (bachelor’s or associate’s) or a certificate (Hoachlander, Sikora, & Horn, 2003). Low-income students, who are often over-represented at community colleges, have completion rates that are even lower. Efforts to increase retention and graduation may be more limited at community colleges than in the traditional four-year institution (Tinto, 2012), due to the type of students that community colleges serve.

Developmental Education

To add to these concerns, due to their “open-door” mission, community colleges often enroll students who are not academically ready for college-level classes, requiring the colleges to spend a lot of time and money on courses designed to bring these students up to college-level work. The public views it as unacceptable to deny students access to college due to inadequate reading, writing, or math skills (Cohen, 1987), and community colleges, due to their status as “open door” institutions, are often charged with helping students develop these skills. In fact, most of these efforts were focused on, and specifically named, “skills” and “skill deficiencies”, and sought to bring these new students up to college-level. This allowed the community colleges to view this type of education in a medical model, where the students were diagnosed and treated (with extra coursework), rather than under a compensatory education model, where access to higher education is viewed as a way to make up for, and move people out of, poverty and discrimination (McGrath & Spear, 1987).

These programs are often referred to as "developmental education". Developmental education at community colleges began in the 1960s, and was primarily designed to serve students who were not prepared for college-level instruction (Center for Community College Student Engagement, 2016). Developmental programs usually provide coursework in reading, writing, and math, sometimes with tutoring and counseling services, designed to prepare students for college-level coursework (Casazza, 1999), and with multiple levels or courses to account for different student skill levels (Center for Community College Student Engagement, 2016). The most common pattern is to have three levels in each subject, although some colleges have as many as five.

Developmental education has also been referred to using other terms, such as *foundational*, *transitional*, *guided*, *basic skills*, *developmental studies*, *college preparatory*, *pre-collegiate*, *academic support*, *learning assistance*, and, most commonly, *remedial education* (Center for Community College Student Engagement, 2016). The terms *developmental education* and *remedial* education are not without some controversy, since students will quickly pick up the expectations of the college they are attending, including the differences implied by terms such as *developmental* and *remedial*, and are influenced by how those expectations validate their presence on campus (Tinto, 2012). Some colleges are completely moving away from the term *developmental education* and replacing it with terms such as *co-requisite building*, *pre-college skill building*, and *acceleration* (Center for Community College Student Engagement, 2016). Although, as noted above, there have been some contention about the terms *developmental education* and *remedial education* and their connotation (Casazza, 1999; Illich, Hagen & McCallister, 2004; Kozeracki, 2002), this study will use the term *developmental education* to refer to all of these types of programs.

Developmental education is becoming more prevalent at community colleges than at four-year colleges and universities. Cohen (1987) reported on a tendency to delegate developmental education to community colleges and to free the state four-year and university systems from that responsibility. Indeed, currently, developmental education has been largely phased out of four-year institutions and is now almost exclusively done by community colleges, in part because four-year college faculty salaries are significantly higher (Bettinger & Long, 2005). It is sometimes difficult to get accurate information about developmental education at some institutions, since they may under-report their developmental education due to its lack of prestige, or in an effort to get higher institutional rankings in U.S. News and World Report (Breneman & Haarlow, 1998).

A large number of new community college students need extensive work on specific skills before they can be admitted to the standard, college-level curriculum (McGrath & Spear, 1987), thus requiring them to enroll in developmental education. Many community college students did not do well in K-12 education, and many have also been out of school for many years (Center for Community College Student Engagement, 2016), and are thus more likely to require developmental education.

Many studies have looked at the large number of students needing developmental education, finding various percentages, but most fall around 60 to 70 percent (Bailey, 2009, Bailey, Jenkins, & Leinbach, 2005; Center for Community College Student Engagement, 2016; Jaggers & Stacey, 2014; Scott-Clayton & Rodriguez, 2012), but possibly going as high as 79% (Jenkins & Boswell, 2002). A study of community colleges participating in Achieving the Dream found that 59% of students were placed in developmental coursework (Bailey, 2009).

The above results mean that developmental students can be a significant percentage of the students that a community college serves. In 2000, Parsad, Lewis and Greene (2003) reported that 42% of all beginning college students at public, two-year institutions enrolled in at least one developmental education course in reading, writing, or mathematics. 44% of community college students enrolled in between one and three developmental courses and 14% enrolled in more than three developmental courses (Attewell, Lavin, Domina, & Levey, 2006).

Developmental education students have different demographic characteristics than other community college students. Adelman (2004) found that 46% of African-American students and 51% of Hispanic students earned credits in developmental math, while only 31% of White students and only 29% of Asian students did so. The developmental student population is older (Burley, Butner, & Cejda, 2001); is often juggling work, family, and school (Edgecombe, 2011; Rutschow, et al., 2011); and has the tendency to have multiple learning deficiencies (Burley, Butler & Cejda, 2001; Rutschow et al., 2011) as compared to the university student population. Women are more likely to enroll in developmental courses (Bettinger & Long, 2005; Penny, White & William, 1998), as are African-American and Hispanic students (Grimes & David, 1999; Penny, White & William, 1998). Older students and students who delay entering college (sometimes characterized as non-traditional students) are also more likely to enroll in developmental courses (Burley, 1997; Calcagno, Crosta, Bailey & Jenkins, 2007; Crisp &

Nora, 2010). First-generation college students are also more likely to be developmental students (Chen, 2005). Differences between developmental and non-developmental students in high school GPA, high school courses taken, and college aspirations have also been found (Bettinger & Long, 2005; Grimes & David, 1999). Looking specifically at developmental mathematics students, Hagedorn, Siadat, Fogel, Nora, and Pascarella (1999) found significant differences in developmental math students and non-developmental math students in gender, ethnicity, and high school GPA.

While community college students often feel that they are ready for college, many of them still require developmental education despite those feelings. According to data from the 2014 Survey of Entering Student Engagement (SENSE), 86% of entering community college students believe that they are academically prepared for college, but 67% of them acknowledge that they will have to take at least one developmental course (Center for Community College Student Engagement, 2016).

The faculty teaching developmental coursework are also a concern in regard to developmental student success. Mesa (2012) studied the relationship between community college students' perceptions about mathematics and their instructors, finding that students had a generally positive self-concept of their mathematical skill, while the instructors' perceptions of the students' skill level were not as positive. Kozeracki (2002) found several issues regarding developmental education faculty. Developmental education faculty members are more likely to be part-time than in other disciplines. Very often, there is no specific training for developmental education faculty. Finally, developmental education is not given much attention in research and practice, perhaps due to a lack of priority or institutional emphasis.

Despite their beliefs, most students that are required to take a developmental education course do enroll in that course. According to data from the 2014 Survey of Entering Student Engagement (SENSE), of the 67% that needed to take a developmental course, 93% of them did enroll in that course. For those entering community college students that did enroll in a developmental math course, 63% believe that the course was appropriate for their mathematics skill level (Center for Community College Student Engagement, 2016). Students that enroll in developmental coursework usually divide into two categories regarding age (Merisotis & Phipps, 2000). Most developmental students are either first time college students straight out of high school (in the age range of 19-21 years), or are significantly older, 30 years old or older, and are returning to college. The distribution of developmental education is also uneven. More students are enrolled in developmental math than in any other area of study (Bahr, 2007).

Developmental courses often cost both students and the community college extra time and money. Students placed into developmental education incur extra costs in terms of both time and money (Melguizo, Hagedorn & Cypers, 2008). Developmental course sequences can be from one to as many as five courses, and generally do not count toward any degree or certificate (Scott-Clayton & Rodriquez, 2012). This can delay a student for as much as five semesters, costing them time, extra educational costs, and forgone earnings (Bailey & Cho, 2010; Hughes & Scott-Clayton, 2011; Levin & Calcagno, 2008).

Estimates of the costs of developmental education at community colleges vary. Strong American Schools (2008) estimated the cost to be between $1.9 and $2.3 billion, costing the average community college student between $1,607 and $2,008 dollars in monetary and opportunity costs. Another study (Noble, Schiel & Sawyer, 2004), estimates the annual costs of developmental education range from $1 billion dollars to perhaps three times that amount. Scott-Clayton & Rodriguez (2012) stated that national annual costs of developmental education for community college students may be as high as $4 billion, while Jaggars & Stacey (2014) estimates the cost of developmental education to be as high as $7 billion.

These costs have led to criticisms of developmental education. There have been arguments that taxpayers are being charged twice for developmental courses, since the material covered by those courses is already being taught in K-12 schools (Merisotis & Phipps, 2000; Saxon & Boylan, 2001). However, other studies (Bailey, Jenkins, Jacobs, & Leinbach, 2003; Schuyler, 1997; Wyman, 1997) have shown that students who complete developmental education courses financially benefit their college, generate a positive return to society, and require less social expenditures.

Traditional Developmental Mathematics Sequences

Most developmental education offerings at colleges (including community colleges) follows a typical sequence, where each course is a full semester in length, meeting between three and five hours a week, is taught in the traditional lecture method, and is the same tuition cost as a regular course, but does not usually count toward degree requirements (Barragan & Cormier, 2013; Grubb, 2013). These developmental sequences can also be rather long, with as many as five courses, to accommodate different academic levels (Scott-Clayton & Rodriquez, 2012). A long developmental mathematics sequence is problematic, not only because there are more courses and, therefore, more likelihood of failure, but there are also more breaks in between courses where students can be lost by not enrolling in the subsequent course (Asera, 2011).

The rationale behind this conventional approach is fairly sensible. Students who do not have the skills for college-level work are exposed to the academic content they need to succeed at the college-level, and, if they complete their developmental sequence, they can move on confidently to college-level work. It also keeps them out of the college-level classes, which benefits both them (since they would tend to perform poorly) and their peers (who might have to endure a slower pace of instruction) (Bailey, Jaggars, & Jenkins, 2015). According to a study by Grubb (2013) of 169 developmental classes at 20 community colleges, most developmental courses have a similar drill-and-practice structure that many of the students have seen before in high school courses, with almost no clarification of why the students need to know these skills. As these students often did not do well in these types of courses in high school, and are made to confront these courses again in college, developmental students, and in particular developmental math students, may confront issues of academic inadequacy.

Placement Testing

Another important factor in developmental education is sorting students so as to determine which students are required to enroll in developmental coursework. Higher education often involves sorting students into different categories, referred to as "the inevitability of the allocative function" by Cohen & Brawer (2008), and for open-access institutions, this includes placement testing students into college-level or developmental coursework, most often in the subjects of English and math. Nearly 92% of two-year colleges use placement test scores to determine placement into developmental coursework (Parsad, Lewis & Greene, 2003). These placement tests are commonly given to students right after admission.

Most community college students are required to take one or more developmental courses based on the results of placement tests such as ACCUPLACER or Compass (Bailey, Jeong, & Cho, 2010; Hughes & Scott-Clayton, 2011). ACCUPLACER is a series of assessment tests in writing, reading, and mathematics given by the College Board (College Board, 2016), while Compass is a series of assessments in writing, reading, and mathematics (including English as a second language) (ACT, 2012). Both tests, along with several others, are commonly used by community colleges for course placement and diagnostic testing.

Open-door institutions often view placement testing and developmental education as necessary to maintain academic standards, by controlling entry into college-level courses (Hadden, 2000), thereby maintaining their legitimacy as postsecondary institutions (Cohen & Brawer, 2008). Many studies find that community college administrators and faculty support mandatory placement tests (Berger, 1997; Hadden, 2000; Perin, 2006). Faculty and administrators at community colleges tend to view their college's developmental assessment system as a system to ensure quality in college-level courses, assuming that, without such screening, the academic quality of their college-level courses would have to be weakened (Hodara, Jaggars, & Karp, 2012; Jaggars & Hodara, 2011).

Unfortunately, students are often unaware of the importance of high-stakes placement tests, and how they could delay their academic progress, and generally do not take the time to prepare for them (Achieving the Dream, et al., 2015). According to data from the 2014 Survey of Entering Student Engagement (SENSE), 87% of entering community college students are required to take a placement test, and most (66%) had advanced notice of that placement test, but only 41% actually prepared for the placement test using the resources that their college provided. Those that did prepare for the test using their college’s resources found those resources helpful (96%) (Center for Community College Student Engagement, 2016). In a survey, college advisors admitted that most students do not know or understand the high-stakes nature of placement tests (Safran & Visher, 2010).

There are some criticisms of large-scale, high stakes placement testing. One concern about placement testing is cultural bias; that is, that the questions on the test may be biased toward specific cultures (usually majority cultures). While placement testing may be culturally biased and not solely indicative of English and math skills, Cohen argues (1987) that such tests are useful because they still identify and prepare students for appropriate coursework, which, in and of itself, may be similarly culturally biased.

Another concern is tracking; that is, the view that placement testing is being used to force students (particularly lower income and minority students) into lower-level educational opportunities. However, Kingan and Alfred (1993) noted that there is support for both the view that assessment is used for tracking and for the view that assessment encourages student persistence and success.

During the 1970s, due in part to some of these criticisms, placement testing and course prerequisites fell out of fashion. Advocates urged ending placement testing based upon the idea that community college students were adults who could make their own educational decisions, including the decision to forego recommended developmental classes. This idea of making developmental coursework optional was seen as encouraging student responsibility (Rounds & Andersen, 1985; Zeitlin & Markus, 1996). The reason behind developmental education then changed from bringing students up to college-level skills (which was being shown to be largely ineffective) to facilitating the mental, moral, and emotional growth of students (McGrath & Spear, 1987). Also, critics, noting the community college's focus on developmental education and vocational programs, argued that community colleges were simply implementing another form of tracking, providing students in lower social classes with some college education, but denying them real class mobility (McGrath & Spear, 1987).

Many, however, argued for the reinstatement of placement testing, noting that the "open door" of community colleges often becomes a revolving door if the college does not define what competencies are needed for their programs, assess if entering students have those competencies, and place them accordingly (Richardson, 1983).

Cohen (1985) stated that it is unconscionable to put unprepared students in college-level classes that they have little chance of passing, and noted the necessity of placement testing students into courses, including developmental courses, if necessary. A similar argument was advanced by Morante (1989). Addressing the issue of tracking, Cohen argued (1987) that the open-door policy of community colleges is to allow students access to the actual higher education implied in the term *college*, rather than just a series of pre-college courses. In the end, legislators and educators concerned with the costs of high failure and dropout rates, reinstituted placement testing and developmental coursework in the late 1970s and 1980s (Cohen & Brawer, 2008; Rounds & Andersen, 1985).

Most of the current literature in developmental education recommends mandatory testing and placement as a "best practice" (Boylan, 2002), despite its criticisms.

However, placement test scores have been shown to be only weakly correlated to student completion or GPA (Armstrong, 2000; Belfield & Crosta, 2012; Jenkins, Jaggers & Roska, 2009; Medhanie, et al, 2012; Scott-Clayton, 2012), and may assign as many as 25% of community college students to the wrong math course (Scott-Clayton, Crosta & Belfield, 2014). These results may be because college readiness is a combination of academic and non-academic factors that placement tests may not be able to measure (Karp & Bork, 2012).

Research on Developmental Education and Student Progression

Developmental education in community colleges has been the focus of a lot of recent research literature (Bailey 2009; Bettinger and Long 2005; Deil-Amen and Rosenbaum 2002; Grubb 2001, 2010; Grubb and Cox 2005; Levin and Calcagno 2008; Melguizo, Hagedorn & Cypers, 2008). Unfortunately, the results for these developmental students are often quite poor, and even lower than community college students in general. Developmental students often have a low chance of completing their developmental coursework or a college-level course. Many students are discouraged from enrolling in developmental classes or do not complete the developmental sequence (Bailey, 2009). In addition, the stigma and frustration of having to take developmental courses, which often cover high school material and are taught similarly to high school classes, frequently lead students to become discouraged and drop out (Deil-Amen & Rosenbaum, 2003). Even if a student passes their first developmental course, there is no guarantee that they will enroll in the next course in sequence. In fact, a significant number of students fail to complete their developmental sequence not by failing a development course, but by not signing up for the next course in sequence (Achieving the Dream, et al., 2015).

Developmental course pass rates tend to be low. Roueche and Roueche (1993) stated that a pass rate of between 61-70% for developmental courses was adequate, but studies show that actual pass rates are much lower. Roska, Jenkins, Jaggers, Zeidenberg and Cho (2009) studied over 24,000 first-time community college students who started in the summer or fall of 2004 in Virginia, following them over four years. They found that the overall pass rate for these students in developmental math was 48%, and that the overall pass rate for gateway math courses (counting those students who never attempted a gateway math course) was around 25%; however, students who actually attempted the gateway math course passed at a 75% rate. However, they noted that those students who were referred to developmental coursework and did not take it had similar pass rates in gateway math courses as the students referred to developmental coursework who did take that coursework before the gateway math course. This would lead toward the conclusion that developmental mathematics coursework does not have any effect on the pass rates of students in their gateway math course.

There have been a few studies on developmental students and developmental sequence completion and gateway course completion. One study found that only 31% of students referred to developmental math complete the full sequence within three years (Bailey, Jeong, & Cho, 2010a), and only a little more than half of those students passed a college-level math course. Another study found that only 33% of students referred to developmental courses complete the sequence, and 30% never enroll in any courses at all (Bailey, Jeong & Cho, 2010b). A study done by Complete College America (2012) showed that only 22% of community college students who were placed in a developmental course in English or math passed a gateway course in that subject within two years. Another study found half of all students in postsecondary education take at least one developmental course, and the completion rate of those students are often well below state and national goals (Achieving the Dream, et al., 2015).

Studies have also shown that students placed lower in their developmental sequence have much lower completion rates than those placed higher in the developmental sequence (Bahr 2008; Bailey, Jeong & Cho, 2010b; Hagedorn and Lester 2006), even for students who stay at the community college for a long period of time (Bahr, 2012; Perry et al. 2010). Cross (1976) noted that most traditionally focused developmental programs are ineffective, and predominantly help only those students who were close to the borderline of college-ready skills. Bailey (2009) found that only 16% of students that require three or more developmental courses in math complete their developmental math sequence in three years. A full analysis of the progression of students through the developmental sequence is therefore important, particularly for those students that have to take multiple courses. If there is no understanding as to why there are differences in where students are lost in their developmental sequences, there cannot be any development of strategies or interventions to address those differences (Bahr, 2012).

A large-scale study (Bailey, Jaggars, & Jenkins, 2015) confirms the conclusions above. In an analysis of approximately 150,000 community college students nationwide, only 30% of students referred to developmental math completed the sequence in three years, and only 16% completed a college-level math course. If the student needed three or more developmental courses, the results were worse: only 15% completed the sequence and 8% completed the college-level course. Interestingly, many of the students in this study who failed to complete the developmental sequence actually did not do so by failing a developmental course. 26% of students who did not complete the developmental math sequence never showed up for the first course, while another 22% passed at least one course, but did not show up for the subsequent course in the sequence. Another 4% actually completed the developmental math sequence, but never enrolled in a college-level math course.

Developmental education has also been found to affect courses in other disciplines. Illich, Hagan & McCallister (2004) found that developmental students that were enrolled in college-level subjects unrelated to the area that they were deficient in had lower pass rates in those college-level courses than non-developmental students, but students that passed their developmental coursework did not have those lower pass rates.

Tinto (2012) urged colleges to assess their student experience and analyze patterns of student progression through the institution, in particular for unprepared or developmental students, undeclared students (students who have not declared a major), low-income students, and students in different programs of study. Many community colleges are analyzing student progression through their programs through the use of intermediate measures; measures that show a student’s progress in steps leading up to, but not including, graduation or completion of a degree program. One of the commonly used intermediate measures, and one with a lot of effect on eventual student completion, is the completion of required developmental education courses and/or the passing of the first college-level English and math course (Ewell, 2008; Ewell, 2011). One way to analyze college completion is through the analysis of momentum points (Adelman, 1999, 2006; Leinbach & Jenkins, 2008). A momentum point is a key point in the curriculum which, when obtained in a timely manner, is associated with progress to degree completion. One of the earliest momentum points is completion of developmental coursework sequences.

Adelman (2006) showed that completion of gatekeeper courses was a critical component of assessment for developmental programs, and an important factor in increasing student success measures, such as degree completion rates. However, in a study performed on two-year college students who graduated in 1992, student success (retention and completion) did not increase for the students placed in developmental coursework, although their success rate did increase if they passed those courses (Attewell, Lavin, Domina, & Levey, 2006). Thus, the key factor for developmental coursework is not being placed into the course, but course completion. Improving the success of students placed into developmental education is therefore critical to achieving college completion goals (Achieving the Dream, et al., 2015).

Developmental education can also be a barrier to a student completing one very important positive factor for graduation; selecting and progressing through a program of study. A study of one community college district showed that only around 50% (and only 30% of low-income students) of community college students are classified as “program concentrators”, meaning that they passed at least three college-level courses in a single field (Jenkins & Weiss, 2011). Since students placed into developmental education often have to complete the developmental sequence to satisfy pre-requisites for a program of study, developmental education students often do not formally select a program, and, even if they do select a program, cannot take courses in their selected program without finishing the developmental sequence, leading to even more frustration and the possibility of dropping out.

Research on Developmental Education and Retention and Completion

While there is ample research on how student characteristics affect community college student retention (Adelman, 2005; Feldman, 1993; Goldrick-Rab, 2007; Pascarella, Wolniak, Pierson, & Terenzini, 2003; Stigler, Givvin, & Thompson, 2010; Waycaster, 2001), there is, however, few studies that investigate the relationship between mathematics instruction and retention (Mesa, 2012). A study by Umoh, Eddy, and Spaulding (1994), on factors that affect retention of developmental mathematics students found that many of the standard factors considered in retention studies (age, gender, parents' education, GPA, academic goal commitment, institutional experience, student academic integration, placement grades, and student performance) had no significant direct effect on developmental student retention, although some academic factors and placement grades had indirect effects. Another study by Bremer, et. al. (2013) found that students with higher placement scores in math were more likely to persist, but enrolling in a developmental mathematics course did not make the student more likely to persist, controlling for demographic variables, reading and writing placement scores, and financial aid. However, two studies have found that students referred to developmental coursework had approximately the same outcomes, whether they enrolled in the developmental courses or not (Calcagno & Long, 2008; Roksa, Jenkins, Jaggars, Zeidenberg, & Cho, 2009).

A study by Fike & Fike (2008) of 9,200 students at one community college found that passing developmental mathematics did have a positive effect on fall-to-fall and fall-to-spring retention, while being referred to and not taking developmental mathematics courses had a negative effect on retention, even compared to taking and failing developmental mathematics courses.

A study of persistence rates and pass rates for the first college-level math course at a Virginia community college by Wolfle (2012) found that developmental students had similar pass rates in their first college-level math course as those who were placed into that course directly. Regarding demographic variables, older students were more likely to pass their first college-level course than traditional-aged students, and minority students were less likely to pass the course than non-minority students. There were no significant effects of age, ethnicity, and developmental coursework on retention rates, however.

Wolfle and Williams (2014) analyzed the effect of developmental coursework on persistence for students at Virginia community colleges, and found that developmental coursework tends to be most effective for traditionally-aged students. Regarding persistence, however, developmental coursework helped the persistence of non-traditional aged students, but hindered the persistence of traditional-aged students. The net result of developmental coursework on student persistence and success was relatively small, however.

However, there are some studies that show that students who complete their developmental sequence have some student outcome gains. Waycaster (2001), in an analysis of math course pass rates at Virginia community colleges found that students who completed the developmental math sequence passed their college-level math course at rates greater than or equal to those students who placed into the course directly, and that retention rates for developmental students were higher than for non-developmental students. Bettinger & Long (2005) found that developmental math students in Ohio community colleges were 15% more likely to transfer to a four-year college than those with similar test scores and high school preparation who did not take developmental math. There was, however, no difference in degree completion or stop-out rates. Studies by Bahr (2008, 2010b) show that students who complete developmental math have comparable long-term outcome completion rates as those students who were not referred to developmental math.

Even if they get past their developmental sequence and the first college-level course, the developmental student’s long-term success prospects are low. Previous research on the success rate of developmental students is somewhat limited (Barnett, 2008; Esch, 2009), however, some studies have emerged. Developmental students at community colleges have been found to be at high risk for dropping out (Roueche & Roueche, 1993; Tinto, 1996). Students who fail in their first semester of coursework, either in a developmental education sequence or by going directly into gateway courses, have a much lower chance of success in college and in life (Center for Community College Student Engagement, 2016). Only about a quarter of community college students who take a developmental course graduate within eight years (Bailey, 2009).

Martorell and McFarlin (2011) found that developmental education has no effect on most student outcome variables, and what effect it did have was often mixed. By analyzing results from community college students in Texas in a similar fashion as Calcagno and Long (2008), they found that developmental education had a negative effect on credits earned and persistence for those students just under the cutoff score. Bettinger & Long (2009), however, found positive effects of developmental mathematics on bachelor degree completion, but also found that it had a negative effect on dropout rates.

Misalignment of Developmental Math

Another concern with the developmental mathematics sequences at community colleges is that they may not be properly aligned to the students and their programs of study. Most developmental coursework is designed based on high-school standards, and may not align with the courses offered by some community college programs (Conley, 2005). For example, most developmental mathematics sequences prepare a student for college algebra; however, the math required for students in majors such as nursing may be quite different from what the developmental mathematics sequence is preparing them (Pritchard, 1995; Achieving the Dream, et al., 2015). In practice, this means that the developmental mathematics sequence focuses on abstract mathematics concepts that the student may not need, and becomes a set of “filters” that many students cannot pass through (Pritchard, 1995), or, as too often the case, the students pass through the developmental sequence, only to struggle and fail in the course that the developmental sequence was preparing them (Tinto, 2012).

As an example, Jaggars & Hodara (2011) found one community college system had an upper-level developmental math course that was designed to prepare students for college algebra, and was required for all developmental math students regardless of their field of study. However, many of the college’s degree programs had college-level math courses in their program that did not require a high amount of algebra (such as courses in quantitative literacy or statistics). So, students that do not succeed in that last upper-level developmental math course may be blocked from advancing to a program that may not require knowledge of that material to complete the program.

For many programs, the more appropriate math course may not be the standard college algebra or calculus course, but might be a course in quantitative literacy or statistics (Achieving the Dream, et al., 2015). Some recent research has suggested the use of structured pathways, which focus on courses in quantitative reasoning rather than the algebra skills necessary for advanced algebra and calculus courses that many students will not need in their programs, in an effort to encourage retention and completion (Clyburn, 2013). Burdman (2015) also urged colleges to consider alternatives to the standard path of developmental education through algebra and pre-calculus, emphasizing courses such as quantitative reasoning and statistics. A similar call for developmental education to have pathways in quantitative reasoning has been advocated by groups such as Jobs for the Future, the Charles A. Dana Center, and Achieving the Dream (Couturier & Cullinane, 2015).

Based on all of the above findings, developmental education, and particularly developmental mathematics, has been identified and criticized as a major barrier to student completion (Bailey, Jeong & Cho, 2010b). Many education advocate groups, such as Achieving the Dream, et al. (2015) have concluded that, based on the completion data for developmental education students, that current structure “is not an on-ramp to college, but a dead-end”, and that developmental math is “the most significant barrier to success”. McClenney (2004) stated that “if students don’t succeed in developmental education, they simply won’t have the opportunity to succeed anywhere else” (p. 15). The ninth president of the Carnegie Foundation, Anthony Bryk, noting that the failure to complete these developmental math courses causes those students to not be able to access vocational or technical programs, or transfer to a four-year institution, summed up the results by noting that “Developmental mathematics is where aspirations go to die” (Clyburn, 2013), and “Developmental mathematics courses represent the graveyard of dreams and aspirations” (Merseth, 2011).

Selection Bias and Other Concerns with Developmental Education Research

Concerns have also been raised about the research on developmental education and student outcomes. One of the main concerns is that of selection bias, where studies do not account for the fact that students in developmental education, by the nature of developmental education, are weaker than the other, college-ready students, at least in the skills ostensibly measured by the placement test (Bailey, Jaggars, & Jenkins, 2015). Most studies on developmental education compare simple descriptive variables of developmental students to non-developmental students (Bettinger & Long, 2005), or do not control for selection bias (Attewell, Lavin, Domina, & Levey, 2006). This makes it difficult to determine if the differences seen are due to differences in developmental and non-developmental students or are due to the developmental classes themselves (Attewell, Lavin, Domina, & Levey, 2006; Bailey, 2009; Bettinger & Long, 2005; Grubb, 2001; Levin & Calcagno, 2008). Gillespie (1993) identified selection bias in several developmental education studies, and others have also found other methodological concerns with developmental education (Goudas & Boylan, 2012). Nora (2009) attributed much of the mixed findings in studies on developmental education to weaknesses in methodology, including ignoring selection bias.

Many studies now discuss the use of statistical techniques to minimize selection bias when investigating developmental education (e.g. Bettinger & Long, 2005; Calcagno, Crosta, Bailey & Jenkins, 2007; Grimes & David, 1999; Penny, White & William, 1998). One option that studies have adopted to control for selection bias has been regression discontinuity designs, comparing students who score just above and just below the cutoff score for referral to developmental classes. However, one criticism of this design is that these studies would not include those students who score very low and would, therefore, have the greatest need and benefit from developmental education (Scott-Clayton & Rodriguez, 2012).

Results of these retention discontinuity studies have been mixed. Some studies of students scoring just above or just below the cutoff of the placement tests show that students scoring just below the cutoff score do not have better outcomes than those placed directly into college-level classes by scoring at or above the cutoff (Calcagno & Long, 2008; Clotfelter, Ladd, Muschkin & Vigdor, 2013; Dadgar, 2012; Martorell & McFarlin, 2011; Scott-Clayton & Rodriguez, 2012; Xu, 2013). Calcagno and Long (2008) found that students at Florida community colleges that had scores close to (but under) the cutoff for developmental math and who took developmental math had higher persistence from the first year to the second year, but insignificant or negative results for any longer-term measures. A similar study at Tennessee community colleges (Boatman & Long, 2010), also found poorer credit and degree completion for those students just under the cutoff value that took developmental coursework. However, a comparison of students in Ohio community colleges (Bettinger & Long, 2009) where placement test score cutoffs were not uniform found that developmental education had a positive effect on retention (for students with the same placement scores).

Bailey, Jaggars, & Jenkins (2015) suggest that the lack of differences in student success between students who are just above or just below the cutoff scores for developmental placement imply that students are unlikely to be harmed by enrolling them directly into the college-level coursework, which would prevent them from getting behind their peers by earning developmental credits as opposed to college-level credits, since students earning developmental credits generally never quite catch up to those who started earning college-level credits (Clotfelter, Ladd, Muschkin & Vigdor, 2013; Scott-Clayton & Rodriguez, 2012).

Another option to account for selection bias is to use propensity score matching; matching developmental students with closely comparable non-developmental students in other categories. A study by Crisp & Delgado (2014) of data from over 23,000 students from the Beginning Postsecondary Students Longitudinal Study, using propensity score matching, found that students enrolling in developmental mathematics courses are significantly different than non-developmental students in terms of gender, minority status, parents earning a college degree, high school GPA, and rigor of mathematics courses taken in high school. The developmental mathematics students were also significantly less likely to transfer to a four-year college or university.

Another study by Bostian (2008) analyzed community college students at an urban community college in the Southeast who transferred to a nearby university. Bostian used propensity score matching to compare those community college students who were placed into developmental education courses, but chose to transfer to the university before completing them, to similar students who took the developmental courses. There was no statistical difference found in the level of academic success between those students who avoided developmental education by transferring and those who took the developmental courses.

Studies that do account for selection bias (using regression discontinuity or propensity score matching) seem to suggest that the negative effects of developmental education can be adequately explained by that selection bias. Bettinger & Long (2005) found that after controlling for student backgrounds, taking developmental courses had no negative effects on student outcomes. Another study (Attewell, Lavin, Domina, & Levey, 2006) found that, after controlling for high school preparation and academic skills, developmental coursework did not negatively affect community college students' chances of earning a two- or four-year degree.

Recently, studies using large datasets or more complex models have been employed (such as Attewell et al. 2006; Bahr 2008, 2010; Moss and Yeaton 2006; Roksa and Calcagno 2010). For example, Bahr (2012) ran a predictive model analysis using a series of logistic regression models based on developmental math students at California community colleges. The results of the analysis showed that the predicted pass rates of students in each of four developmental math courses stayed relatively stable (between 52% and 64%) for each course in the sequence when students took the courses in sequence, but delaying the next course led to lower pass rates. Others have suggested using more complex models to analyze developmental mathematics sequences such as hierarchical or cluster analytic models (see Bahr, 2009; Bahr, 2010a).

Looking at completion rates of developmental math students is further complicated by the fact that there is often not a single gateway course in mathematics at most community colleges. A study by Jaggers & Hodara (2011) showed that at a single community college system, the first college-level mathematics course could be a course in college algebra, introductory statistics, or the history and culture of mathematics. In North Carolina, the options include college algebra, introductory statistics, a survey course in mathematical topics, a mathematical measurements course, or a course in algebra and trigonometry designed for engineering technology students (North Carolina Community College System, 2012).

Several studies have also looked at the progression rates of developmental students toward intermediate measures, credential completions, and transfer to four-year colleges (Bahr 2009; Bailey, Jeong & Cho, 2010b; Hagedorn and Lester 2006; Perry, Bahr, Rosin & Woodward. 2010; Waycaster 2001). Studies have found that developmental education may positively impact a student's first year in college (Weissman, Silk & Bulakowski, 1997) and first-year retention (Calcagno, 2007; Calcagno & Long, 2008), but does not seem to affect longer term outcomes (Calcagno, 2007).

Finally, some studies have looked at developmental course grades and how those grades affect future academic performance, noting that it is important that developmental math students not only pass their developmental math courses, but pass them with sufficient understanding of the concepts so that they can succeed in their next math course (Hagedorn, Lester & Cypers, 2010; Bahr, 2010b). Hagedorn, Lester and Cypers (2010) found that students passing their developmental courses with a C often had similar experiences as those who earned a D or F, suggesting that passing a developmental course with a C is insufficient to prepare students for their next math course.

Self-efficacy and Developmental Mathematics

For developmental math students, their chances of success are reduced by not only their academic skills, but by non-academic factors as well, and specifically their sense of self-efficacy. Developmental math students often have a self-concept of failure, developed through their past experience of repeated failures in our education system (Strowbridge, 1987). The challenge is to build strong positive attitudes and diminish negative attitudes about math in these students.

Bandura’s (1986) social cognitive theory states that a student’s interpretation of their performance changes their perception of their own self-efficacy, which then affects future performance. If a student feels confident in their performance in college, this would then encourage them to put forth more effort in more challenging and complex tasks and courses. This effect is even more pronounced for students who struggled with school in the past (Zajacova, Lynch, & Espenshade, 2005; Voung, Brown-Welty, & Tracz, 2010). Another study by Zientek, Ozel, Fong and Griffen (2013) found that a student’s sense of self-efficacy was a predictor of student success, after attendance and repeating a course. Therefore, for developmental math students, being able to see themselves succeeding academically is as important as gaining the actual academic skills (Hall & Ponton, 2005).

Also, Dweck (2006) noted that when students initially fail at a challenge, they can adopt two mindsets. One, the fixed mindset, asserts that the challenge is beyond their ability and not worth attempting, while the other, the growth mindset, makes them think that they will eventually be able to complete the challenge if they work hard enough. Many studies have shown that helping students learn that their academic abilities are not fixed improves motivation, persistence, and eventual success (Aronson, Fried, & Good, 2002; Yeager & Dweck, 2012).

New Approaches to Developmental Math

In the early 2000s, based on the available research at the time (which showed similar results to the studies mentioned above), a re-examination of developmental education was called for due to poor progression of students through these developmental education sequences, particularly developmental math (Center for Community College Student Engagement, 2016). In 2002, the National Center for Developmental Education recommended 33 best practices for developmental education at community colleges, including making developmental assessment and placement mandatory, teaching critical thinking, and creating a clearly defined mission, goals, and priorities for developmental education (Bailey, Jaggars, & Jenkins, 2015).

Boylan (2002) identified four key areas of improvement for developmental education. First, there is a mismatch between the skills high schools teach students and what skills colleges expect students to know for college-level courses. Second, assessment practices are not properly focused, making students take a whole course when they may only need review of one or two concepts. Third, there is often no system to guide students through the developmental process and give them additional support to transition to college-level courses. Finally, developmental courses are often just a review of high school courses, and are not taught with the student in mind. Boylan also encouraged mastery learning, which relies on compact units of instruction, frequent reenforcement of concepts, and uses frequent testing to ensure that the concepts are learned.

Tinto (2012) also encouraged colleges to analyze their current developmental education sequences, encouraging them to review their pedagogy and assessment practices, ensure that the developmental coursework and subsequent college-level coursework was aligned, and accelerate students through the curriculum, possibly through placing some of them directly into college-level classes with additional instruction.

Unfortunately, a lot of these efforts in developmental education met with little success. In an analysis of Achieving the Dream interventions, about half of the interventions were targeted toward developmental students (Bailey, Jaggars, & Jenkins, 2015). Despite these efforts, analyses on developmental coursework completion rates and gateway course pass rates showed that there was essentially no change in any of these metrics, with the exception of a slightly positive effect in gateway English course pass rates (Rutschow, et. al., 2011). Another analysis two years later showed the same results (Mayer, et. al., 2014).

An analysis of efforts at 11 community colleges in California as part of the Strengthening Pre-collegiate Education at Community Colleges research project found that, after 3 years and a large range of developmental education efforts, there were only modest increases in student completion. Failure rates for developmental mathematics remained high, with technology and curriculum changes posting only small completion rate increases. The efforts that had the most increases were also highly immersive and intensive and were, therefore, difficult to scale (Asera, 2011).

These poor results for developmental students led several college research groups and advocates, such as Achieving the Dream, American Association of Community Colleges, Charles A. Dana Center, Complete College America, Education Commission of the States, & Jobs for the Future (2015), to conclude that the most commonly used design of developmental education, where students must complete a sequence of several semester-long courses before enrolling in college-level courses, does not work, and to urge colleges to find new approaches to developmental education that allow all students, no matter their skill level, to have a realistic chance to earn a college credential. These groups strongly encourage colleges to change their focus away from trying to improve pass rates in individual developmental courses and toward improving pass rates in gateway courses and progress toward a credential.

Many community colleges have, over the last decade, made a concerted effort to reform the traditional system of developmental education (Bailey, Jaggars, & Jenkins, 2015). For example, in 2009, several state community college systems (including North Carolina) partnered with the Developmental Education Initiative (DEI) and Jobs for the Future to build the DEI State Policy Framework to help reform developmental education. These efforts focused on five areas: data and performance management, developmental education innovation and redesign, aligning expectations of courses with K-12 education, assessment and placement, and finance. In 2011, the results of their efforts were compiled and showed that the states in the DEI initiative had made a large amount of progress in developmental education (even during difficult financial times), particularly regarding data capacity, large-scale redesigns of their developmental education sequences, and in assessing underprepared students and placing them in developmental coursework (Altstadt, 2012).

The most common new approach to developmental mathematics is through the use of technology, specifically online or blended instruction. However, the results of these efforts are often poor. Many studies have shown no significant difference between courses taught in traditional, online, or blended (partially traditional and partially online) formats (see Chernish, DeFranco, Lindner & Dooley, 2005; Dutton, Dutton & Perry, 2002; Fredrickson, Reed & Clifford, 2005; Herman & Bannister, 2007; Hodge-Hardin, 1997; Kromrey & Purdom, 1995; Neuhauser, 2002; Sauers & Walker, 2004; Scheetz & Gunter, 2004), but many of these studies are on traditional students, which would not account for the higher proportion of non-traditional students that make up the community college developmental mathematics student population.

A study by Ashby, Sadera, & McNary (2011), on similar developmental math courses taught in traditional (face-to-face), online, and blended (half traditional and half online) formats found that the blended format was the least effective, although removing students who did not complete all assignments made the traditional format the least effective. Another study by Bendickson (2004) found that retention rates in computer-based developmental math courses were as low as or lower than those taught in the traditional format.

Zavarella and Ignash (2009) showed that students in fully online or hybrid developmental math courses had higher withdrawal rates than those in traditional, lecture-based courses, meaning that the learning environment may have an effect on the completion rates of developmental mathematics students. However, these results may be due to the reasons why students selected the format of the course. As part of the study, students answered a survey about the reasons behind their choice of format. Students who selected the format of the course because it met their personal needs withdrew from the course at a significantly lower rate, while students who chose a format based on perceived need or access (perhaps thinking online courses were easier to access or less time-consuming) withdrew at a significantly higher rate.

Finally, a review study by the Office of Vocational and Adult Education (2005), part of the U.S. Department of Education, reviewed several studies of the use of technology in developmental math courses. While the study found that there was little scientific basis to support new instructional techniques, it found a consensus opinion that technology was best used to support, rather than replace, traditional instruction.

As an alternative to the fully online or blended technology model, among the new approaches to developmental mathematics is computer assisted developmental math, where the student uses a web-based learning system (math tutorial software such as ALEKS or MyMathLabs) offered in a computer lab, working at their own pace, with access to instructors present in the lab (Center for Community College Student Engagement, 2016). A review of studies by Epper and Baker (2009) found support in the use of alternate instructional methodologies, including computer assisted instruction and course redesign (moving courses from the traditional format into a computer lab with computer assisted instructional support).

Another option to help students through the developmental sequence is to accelerate the coursework by compressing the developmental sequence; that is, reducing the number of contact hours in the sequence, usually by aligning the coursework with the college-level gateway course or by eliminating redundancies in the sequence (Bailey, Jaggars, & Jenkins, 2015). Some colleges are experimenting with these accelerated developmental courses, with specific remediation directed toward areas identified by competency tests (Liebowitz & Taylor, 2004). Hern (2012) studied student progression rates at a California community college, comparing a traditional developmental math course sequence (of two courses) leading to a statistics gateway course versus an accelerated developmental course sequence with one developmental math course before the gateway statistics course. Students in the accelerated sequence completed the gateway course at much higher rates than those in the traditional path, regardless of their original placement. These results are attributed by Hern to reducing the number of “exit points” (points where the student may leave the sequence, either by failing a course or failing to enroll in the subsequent course) in the sequence, thereby having less chance of a student dropping out of the sequence before completion.

Multiple Measures

As mentioned above, placement into developmental education by the use of a single high-stakes test has been questioned, leading to calls for supplementing placement test data with other measures of assessment (Center for Community College Student Engagement, 2016). Many groups have suggested that placement not be used solely as a screening method to deny students the ability to take college-level courses; rather, they should be used to determine the academic and non-academic supports that a student needs to succeed in gateway courses (Achieving the Dream, et al., 2015). Saxon & Morante (2014) questioned the validity of placement solely by placement test, arguing that these placement test scores are being used inappropriately, and should be supplemented with other measures (such as high school rank or high school GPA).

There are three reasons why a single placement test can misplace students. First, as mentioned previously, incoming students often are not aware of how important these tests are, partially because colleges, in an effort to gain enrollment, tend to downplay the tests' importance (Venezia, Bracco, & Nodine, 2010), and partially because students often do not prepare for the tests, or tend not to take the tests too seriously (Jaggars & Hodara, 2011). Second, the placement test may be poorly aligned with the expectation of college-level coursework, as described above. Finally, the skills assessed on the placement test, which is often multiple choice, may not be all of the skills needed to be successful in college (Bailey, Jaggars, & Jenkins, 2015).

Most placement tests have cutoff scores, where students scoring below those values are placed in, or advised to enroll in, developmental coursework. However, no matter how good the test is, there is the possibility of incorrect placement, particularly for those students scoring close to the cutoff score. Incorrect placement has several detrimental effects, from the student feeling either out of place in the class or unchallenged by the coursework, to the faculty member not being able to effectively teach all of the students due to the wide range of student preparedness (Tinto, 2012). Misplacement rates of placement tests was shown to be as high as 33.4 percent in algebra in one study (Cordrey, 1984). A study by the Community College Research Center found that, at one community college system, around 40 to 50% of the students placed into developmental math (using a placement test) could have passed a gateway math course without taking any developmental coursework (Clayton, 2012). In fact, in 2015, ACT announced that it would be phasing out the Compass test by the end of 2016 due to concerns about the test putting too many students in developmental coursework who may have been able to succeed in college-level courses (Fain, 2015).

Due to the above concerns regarding placing students solely by the scores of a placement test, many colleges and community college system are experimenting with different types of assessment and placement reform. One common initiative is to use other academic metrics (such as high school GPA, high school class rank, or high school credits earned) in conjunction with, or as a replacement for, placement tests to assess students. This is commonly referred to as multiple measures.

There are several studies that support the idea that other academic metrics can be predictive of student success in college. One study from the Community College Research Center found that, at one community college system, high school GPA was more predictive of student success than placement tests (Scott-Clayton, 2012). Incorporating high school GPA into placement criteria has been shown to place students into coursework (developmental or college-level) more appropriately (Clayton, 2012). Other studies have shown that students who complete Algebra II in high school are more than twice as likely to graduate from college (Adelman, 1999; Evan, Gray & Olchefske, 2006).

According to Noble and Sawyer (2004), using multiple measures significantly increases the accuracy of student placement over placement test results alone. A study by Marwick (2004) on Hispanic students also found that multiple measures increased the accuracy of placement. Similar results have been found by Gordon (1999), using computer adaptive testing, and Armstrong (2000), using high school performance, although the high variability in instructor grading makes that measure less ideal.

Studies of multiple measures of placement have also shown (Belfield & Crosta, 2012; Scott-Clayton, 2012) that high school GPA and high school course completion are positively correlated with college-level student outcomes, and (Ngo & Kwon, 2015) have shown that students placed into college-level mathematics using high school GPA and math courses taken in high school have similar pass rates as those placed into college-level mathematics based on placement test scores. One simulation performed by J. Scott-Clayton at the Community College Research Center compared placement by test scores alone to placement using the better result between test scores and high school performance, and found that the number of students placed in developmental classes would fall, and there would also be a decline in placement errors (Bailey, Jaggars, & Jenkins, 2015).

Emporium Model

Another popular model for developmental course redesign is the emporium model. The emporium model of teaching mathematics was designed at Virginia Tech (Twigg, 2011), as part of the National Center for Academic Transformation's (NCAT) Program in Course Redesign. The Program in Course Redesign asked 30 institutions to redesign large-enrollment introductory level classes to increase the use of technology, increase student learning, and reduce costs. Virginia Tech redesigned its linear algebra course by combining all sections of linear algebra into one large computer lab, open twenty-four hours a day, seven days a week (Olsen, 1999). Students would learn the material at their own pace using online materials, complete with video lectures, lecture notes, interactive tutorials, exercises, electronic textbooks, solutions to frequently asked questions, and online quizzes (Twigg, 2011). Instructors, graduate teaching assistants, and peer tutors are present in the labs to give students assistance as they needed it. This model increased the pass rate of the course by almost 7 percent (from 80.5% to 87.25%, a statistically significant improvement) in the first four years of implementation, while decreasing the instructional cost per student by $53 (from $77 to $24) (Olsen, 1999).

This model was replicated at the University of Alabama (for a developmental math course, Intermediate Algebra) and at the University of Idaho-Moscow (for two pre-calculus courses designed for students not ready for regular college math courses) (Twigg, 2011). Both universities made modifications to the Virginia Tech emporium model, including mandatory attendance, a mandatory weekly group meeting, smaller computer labs, and use of commercial software packages (such as ALEKS, Hawkes Learning Systems, or MyMathLab). Both programs also saw increases in the pass rate of the courses under the emporium method, particularly for minority students (African-American students in the University of Alabama study, Hispanic students in the University of Idaho-Moscow study).

After these initial successes of the emporium model at the university level, the model was then replicated at two community colleges in Tennessee in 2006 for all of its developmental courses (Bassett & Frost, 2010; Squires, Faulkner & Hite, 2009; Twigg, 2011). Further changes were made to the model to adapt it for use at community colleges, including fixed instructional hours, modularization of the material covered, and mastery learning, where a student must show mastery of the material taught through completion of homework assignments before proceeding to the next topic. Analysis of the data from these two community colleges showed that pass rates for the developmental math courses taught by the emporium method increased by 17 percentage points, and the pass rate of those students in the subsequent college-level math courses increased by 10 percentage points.

NCAT attributes the success of the emporium model to four core principles (Twigg, 2011). First, students spend the majority of their time working on the problems themselves, rather than listening to an instructor describe how to solve a problem. Second, students can go through the material at their own pace, quickly proceeding through material that they have mastered and taking more time on areas that prove more difficult, rather than being forced to the schedule dictated by the instructor’s lectures. Third, students are given instant feedback from the computer-based homework problems they practice, and can get individualized and immediate assistance when they encounter problems, rather than having to wait for the return of homework papers and tests. Finally, students are required to participate and do the homework problems as part of their grade for the course, providing a needed structure to the course that unstructured, open-entry/open-exit instructional models (typical of some online learning methods) do not have.

Developmental Course Redesign at North Carolina Community Colleges

In North Carolina, the legislators and administrators of community colleges, concerned with the completion and graduation rates of developmental community college students at their institutions, commissioned a study of those students and their progression and placement rates. This analysis, performed by the Community College Research Center (described by Morrissey and Liston, 2012, and detailed in Belfield &

Crosta, 2012), found that 69% of recent high school graduates who enrolled at a North Carolina community college required developmental coursework, and found that only 8% of the students placed into the lowest level of developmental math eventually passed a college-level math course. Also, an estimated 30% of students placed by their current placement test policies were misplaced, and that implementing a high school GPA placement requirement would be expected to reduce the misplacement percentage to 15%.

Based on the results of this analysis, the North Carolina Community College System chose to change its developmental education model for mathematics, and to implement a multiple measures criterion for developmental placement. The developmental education model would be based on eight shorter modules as opposed to three semester-long courses, and would allow for colleges to choose a traditional, online, or emporium model of instruction for those modules. The multiple measures placement criteria would use high school GPA and mathematics courses taken in high school, based upon the research mentioned above.

The emporium model instituted by the North Carolina Community College System (2012), and as used by the college in this study, is similar to the Tennessee community college model described above. It consists of a module-based developmental math sequence. Colleges can choose to teach modules individually, or use module shells, where students select the number of modules they wish to complete in one semester. The students are placed in a class, which meets in the developmental math computer lab at set times. Attendance in the class during the specified class times is mandatory; however, students can come to the computer lab outside of their scheduled class hours to work on the material, using one of the 4 extra computers that are not being used by the class currently in the lab. Students learn the material from an interactive computer software package (MyMathLab) in a developmental math computer lab, staffed by mathematics instructors and teaching assistants five days a week during the hours the college is open (generally 8 am to 9 pm). When the developmental math computer is not open or if all computers in the lab are occupied, the student can access all course material (except for tests) from any computer with internet access. Tests, however, are password-protected, and can only be taken during set class times or at a special lab time on Fridays.

The Multiple Measures of Placement criterion (Morrissey, 2013; North Carolina Community College System, 2011), started in Fall 2013, allowed for placement of students directly into college-level mathematics courses if they had a high school GPA of 2.6 or higher and four math courses in high school, with at least one high school credit in mathematics above Algebra II. While the new placement requirements would only be made mandatory in Fall 2015, many community colleges in the system chose to implement Multiple Measures earlier.

It appears that, based on preliminary data, the Multiple Measures of Placement criterion has had some positive effects. One analysis of the policy was performed at Davidson County Community College (a college that implemented the policy early) over the 2013-2014 and 2014-2015 academic years. This study compared the completion rate of gateway courses for students placed using the Multiple Measures criterion (described above) with those placed by placement test, SAT/ACT score, or completing the appropriate developmental education sequence. In math, 65% placed using Multiple

Measures successfully completed the gateway course, as compared to 48% placed by other means (Center for Community College Student Engagement, 2016).

Markov Chains

This study uses a Markov chain model to compare the progression of students under the old developmental mathematics sequence to the progression of students under the new redesigned developmental mathematics sequence. As described previously, a Markov chain is a series of states or stages with transition probabilities denoting the likelihood of a participant moving from one state to another in one unit of time (Norris, 1997). These probabilities are required to fulfill the Markov property, meaning that the probability of transitioning from one state to another cannot be dependent on any previous states except for the current state (i.e. the model is “memoryless”).

While there are no specific references in the literature to analyses of developmental mathematic progression at community colleges using Markov chains, there have been progression analyses using Markov chains in other areas of education.

In four-year colleges and universities, Herrera (2006) used a Markov chain student flow model to predict student progression through the four statuses of a four-year degree (freshman, sophomore, junior, senior status), and eventual graduation, based upon variables before and after admission to the college. In another study, Nicholls (2007) used a Markov chain design to analyze the completion rates of master’s and doctoral students in a business program at an Australian university, and compare the progression and completion rates of those students based on full- or part-time status. Borden and Dalphin (1998) uses a Markov chain model to simulate student enrollment and progression at a four-year college to observe changes in retention and graduation rates based on changes in credit load (full-time vs. part-time) and grade performance. Wainwright (2007) used a Markov chain model to model the transitions of university undergraduates at a regional state university from entering freshman to when they left the college, either by graduating, being dismissed due to poor academic performance, or leaving for other reasons. A similar study to Wainwright by Smith-Cuyana and Munoz-Hernandez (2001) used the model to study the transitions of entering freshman at a regional state university, paying particular attention to the status that withdrawing students held (freshman, sophomore, junior, or senior).

Markov chains have also been used in secondary education. McFarland (2006) used a Markov chain design to analyze the mathematics course paths of high school students at two high schools, and if certain groups of variables about the students (demographic variables, grades, and ability levels) were able to predict their transitions through these course paths.

Markov chains have several advantages that facilitate their use in progression studies. Markov chain models are useful for analyzing data with multiple states, and where participants can start and end in different states. These models can be used for cross-sectional historical data, and can be started at any time that data exists (Armacost & Wilson, 2007). Markov chains allow for participants to be entered into the model at any state in the chain, allowing for participants that have different starting points to be analyzed together, rather than restricting analyses to cohorts that all start at a specific state, thus possibly reducing selection bias. Also, Markov chains can accommodate multiple pathways of completion (i.e. different first college-level courses), whereas other designs may not be able to adjust. Finally, Markov chains can also help identify specific points of difficulty in the model (where the transition probabilities are lowest), so as to allow for specific initiatives to be targeted toward those specific states.

Markov chain models, however, have some limitations. Transition matrices can become extremely large as the number of states increase (changing the number of states from n to $n + 1$ adds $n(n + 1)$ new transitions to the transition matrix), so the model is best used when the total number or states can remain small. This means that, for enrollment and progression studies, student populations are often aggregated together into a single group or state rather than separating them into separate groups or states (Kraft & Jarvis, 2005). The Markov chain model also assumes, over the length of time that the data set spans, that there are no changes in transition probabilities based on time; that is, the probability of transitioning from one state to another does not change from the beginning to the end of the time frame of the study. However, any college will naturally change by adding or ending programs, changing its student populations, and changing the distribution of course offerings (such as increasing distant education offerings) (University of Central Florida, 2005). Therefore, Markov chain models should have restricted time frames, perhaps no more than 10 years.

Conclusion

College completion is a subject of increasing interest in education and in the general public, and even more so for community colleges, who, by their nature and mission, often serve those populations most in need of the benefits of higher education. Unfortunately, retention and completion rates for students at community colleges have been low, particularly for students who are not deemed “college-ready”.

For these students, many community colleges provide developmental education, mostly in the fields of reading, writing, and math, to allow these students to work on specific skills so that they can be successful in college-level coursework. Many of these developmental education programs have multiple levels to accommodate differing levels of academic preparedness, which are necessary due to the “open door” mission of the community college. Many colleges use placement tests (albeit with some concerns about accuracy and bias) to determine which students need developmental education and where to place those students, often with the students not having a full understanding of the importance of the placement test. Consequently, a large percentage, and often a majority, of community college students are required to take these developmental education courses, with a disproportionate amount of them being minority, women, and non-traditionally aged. These courses, while being necessary (although that is debated), cost both the students and the colleges extra time and money, since developmental education courses usually do not count toward a student’s degree. Therefore, finding the most efficient way to offer developmental education, in terms of time and efficacy of instruction, is an important step toward addressing concerns about college completion.

However, as seen above, most research studies on developmental education students show that they have very low rates of developmental sequence completion, gateway course completion, retention, and graduation, particularly regarding developmental mathematics. While there are a variety of rationales for these results, most of the research has concluded that the traditional approach to developmental mathematics, modeled after high school courses and covering similar material as high school courses, is not optimal for developmental students, who often did not do well in those courses when they were in high school. There are also concerns about the research models used in these studies, since many of them have no controls for selection bias.

Since it appears that the traditional approach is not working, many community colleges and community college systems have experimented with new placement systems, new instructional techniques, and new course sequences. Some colleges are using other criteria for placement besides tests, often referred to as multiple measures. Other colleges are trying using online or blended instruction, and other models such as the emporium model, to teach developmental mathematics. Still others are reducing the length of the developmental sequence, moving to co-requisite developmental courses alongside gateway courses, or even making developmental coursework optional, all with differing degree of success, and often with concerns about selection bias.

With this research in mind, the North Carolina Community College System implemented a change in its developmental mathematics sequence and placement policies starting in 2012. The overall goal of these efforts was to help developmental mathematics students complete their developmental mathematics sequence more quickly, and pass their gateway mathematics course at higher rates, so as to increase their chances of completing college. This initiative should be formally tested to determine its efficacy. However, concerns about selection bias have been raised about previous research into developmental mathematics, so a valid test of this new developmental sequence should be designed so as to minimize such bias.

As there are several different levels of developmental mathematics (to account for differing student academic levels in math, as mentioned above) and several different possible gateway mathematics courses, standard methodological techniques do not work as well to examine this type of course structure, leading to selection bias. However, a different type of model, based on Markov chains, would allow for the multiple points of entry and exit from the developmental math sequence, and would help to address selection bias concerns. While the Markov chain model has not been specifically used to evaluate developmental mathematics sequences at community colleges, it has been used in similar situations at other types of colleges, leading to the possibility that the Markov chain model could be used as a tool for the comparison of these two different models of developmental mathematics.

CHAPTER 3: METHODOLOGY

Overview

As we have seen in the literature review, a significant majority of community college students are required to take developmental courses (Bailey, 2009; Bailey, Jenkins, & Leinbach, 2005; Center for Community College Student Engagement, 2016; Jaggers & Stacey, 2014; Jenkins & Boswell, 2002; Scott-Clayton & Rodriguez, 2012), but many of them do not succeed in those courses, and, indeed, in completing their degree (Bailey, 2009; Bailey, Jaggars, & Jenkins, 2015; Bailey, Jeong, & Cho, 2010a; Bailey, Jeong & Cho, 2010b; Calcagno and Long, 2008; Jenkins & Weiss, 2011; Roueche & Roueche, 1993; Tinto, 1996). As mathematics is the most prevalent area requiring developmental education (Bahr, 2007), studies of developmental mathematics are of critical importance to help with effort to increase college completion.

However, as we have seen, many studies suffer from selection bias issues (Attewell, Lavin, Domina, & Levey, 2006; Bailey, 2009; Bettinger & Long, 2005; Gillespie, 1993; Goudas & Boylan, 2012; Grubb, 2001; Levin & Calcagno, 2008; Nora, 2009). This suggests that other approaches may be necessary to properly analyze developmental mathematics sequences. One way to consider these approaches is to look at the key rationale behind developmental education; that is, in preparing students for the next course in sequence.

Ideally, assuming that students are properly assigned to the appropriate developmental mathematics course and learn the material covered in that course, those students who pass the developmental math course should have similar progression and pass rates as those who were placed into the next course in sequence directly. As an example, consider a simple developmental mathematics sequence of two developmental math courses (D1 and D2) leading to a gateway math course (G). If a student is placed correctly into D1, learns that material (as evidenced by passing the course), then (barring concerns about delays and stop-outs) when they go to the next course in sequence (D2), they should, ideally, have the same chance of passing D2 as a student placed directly into D2. Similarly, should this student learn the material in D2 (again, evidenced by passing the course), they should have the same chance of passing the gateway course G as a student placed directly into G.

From this perspective, a student placed into D1 that passed D1 and proceeded to D2 would be in the same position, or state, as a student placed directly into D2. This means that, ideally, their progression through the remainder of the sequence should not be dependent upon their previous status as a student placed (initially) in D1. In short, this means that their previous status of being a student in D1 is “forgotten”, and that, in a sense, the sequence is “memoryless”.

This rationale fits well with the Markov property present in Markov chains (Norris, 1997), suggesting that an approach using Markov chains might be suitable for analyzing developmental mathematics sequences. As mentioned previously, Markov chains also have several advantages that facilitate their use in progression studies (Armacost & Wilson, 2007), such as the ability to start analyses at any time, the ability to handle students being placed in different courses, having different gateway math courses and thus different paths to completion, and the ability to find points of difficulty within the sequence.

This perspective, along with similar studies that used Markov chains to analyze student progression in other contexts (Borden & Dalphin, 1998; Herrera, 2006; McFarland, 2006; Nicholls, 2007; Smith-Cuyana & Munoz-Hernandez, 2001; Wainwright, 2007) served as the impetus behind this study.

The Dataset

This study took place at one medium-sized suburban community college in North Carolina, designated Mid-Central Community College (MCCC). Mid-Central Community College currently serves approximately 9,000 students in its curricular programs, with an overall full-time equivalent (FTE) count of around 5,000 FTE in one academic year. Analysis of student demographics indicate that students at the college are majority female (approximately 60% female), and white (70% white, 20% African American, 10% other minority). Other than an increase in the percentage of students in the other minority category (specifically those of Hispanic origin), these demographic characteristics have remained fairly consistent over the timeframe of the study.

This study's timeframe covered the period from Fall Semester 2007 to Summer Semester 2015. Additional student placement and transfer course information was collected prior to the main timeframe of the study (for placement and assumption checking purposes), and an added year after the main analysis timeframe (Fall Semester 2015 to Summer Semester 2016) was used to determine if those students currently in the developmental sequence finished the developmental sequence and their gateway mathematics course.

The main timeframe of the study (Fall Semester 2007 to Summer Semester 2014) was divided into five years (Fall Semester 2007 to Summer Semester 2012) under the old developmental math sequence (four semester-long courses, MAT 050, MAT 060, MAT 070, and MAT 080), and three years (Fall Semester 2012 to Summer Semester 2015) under the new developmental math sequence (eight modules, DMA 010-080, covering the material in MAT 060, MAT 070, and MAT 080, with the old MAT 050 course retained). These periods of time allow students an ample opportunity to complete the sequence and the subsequent gateway math course within the timeframe of the study. Previous to Fall Semester 2007, MCCC used a different student records system, and there were concerns that the migration of student course records was not performed correctly, leading to the decision to start the study at that time.

While under the old developmental mathematics sequence, MCCC offered four semester-long courses in developmental mathematics, called MAT 050 (Basic Math Skills), MAT 060 (Essential Mathematics), MAT 070 (Introductory Algebra), and MAT 080 (Intermediate Algebra) (North Carolina Community College System, 2016c). The first, and lowest-level of these courses, MAT 050, usually was only scheduled for a single section per semester, and was often cancelled due to low enrollment and the students needing that level of developmental mathematics coursework sent to a non-credit continuing education course. These MAT 050 students will be used in the study, but caution will be exercised in drawing conclusions from this group of students. As for the gateway mathematics courses, MCCC offered the following gateway mathematics courses (given along with their developmental mathematics pre-requisites):

- MAT 115 (Mathematical Models): Pre-requisite of MAT 070

- MAT 121 (Algebra/Trigonometry I): Pre-requisite of MAT 070
- MAT 140 (Survey of Mathematics): Pre-requisite of MAT 070
- MAT 151 (Statistics I): Pre-requisite of MAT 080
- MAT 161 (College Algebra): Pre-requisite of MAT 080
- MAT 171/171A (Precalculus Algebra): Pre-requisite of MAT 080

The North Carolina Community College System allows colleges to choose either MAT 161 or 171 (or possibly both) as their college algebra gateway course. The main difference between the two courses is the inclusion of material covering higher-order polynomials, radical and rational expressions and equations. This is accomplished mainly through adding an extra lab component to the standard MAT 171 course (called MAT 171A: Precalculus Algebra Lab), increasing the number of contact hours from three contact hours for MAT 161 to five contact hours for MAT 171 and MAT 171A. In Fall Semester of 2011, MCCC decided to change from offering MAT 161 to offering MAT 171 and MAT 171A; however, MAT 171 and MAT 171A courses are offered together in a block schedule (students are registered for both courses at the same time, taught consecutively with the same instructor in the same classroom, the lab beginning immediately after the conclusion of the standard course) and are graded using the same grade for both the standard course and the lab. Both the MAT 161 and MAT 171/171A courses were included in this study, with the study using only the grades for the standard MAT 171 course (since the lab grades will be identical).

After the redesign of developmental mathematics (North Carolina Community College System, 2012), the developmental mathematics sequence consists of eight modules, denoted DMA 010-080 (North Carolina Community College System, 2016a), along with the aforementioned MAT 050. These courses cover the following topics:

- DMA 010: Operations with Integers
- DMA 020: Fractions and Decimals
- DMA 030: Proportion/Ratio/Rate/Percent
- DMA 040: Expressions/Linear Equations/Inequalities
- DMA 050: Graphs/Equations of Lines
- DMA 060: Polynomials/Quadratic Applications
- DMA 070: Rational Expressions and Equations
- DMA 080: Radical Expressions and Equations

The individual colleges in the North Carolina Community College System were allowed to choose whether to deliver these courses as single modules, or collect them into module shells to make semester-long courses. MCCC chose to use the module shell approach, allowing students to choose to take one, two, or three modules within a semester (denoted by the course numbers DMS 001, DMS 002 or DMS 003, with the number indicating the number of modules chosen). The number of modules the student chose determined the amount of time the student will be in class and the length of the course (1 module = 2 hours per week for 8 weeks, 2 modules = 2 hours per week for 16 weeks, 3 modules = 3 hours per week for 16 weeks).

As students can earn partial credit (credit for the modules they complete, but not passing the course by not passing all the modules they selected in the shell course), a separate spreadsheet of students and the modules they completed by semester was maintained by the Mathematics Department at MCCC, and was used in this study to track student completion of modules as opposed to using standard grade reports.

To help colleges with the changed in the developmental mathematics sequence, the North Carolina Community College System developed a crosswalk to show the correspondence between the two developmental mathematics systems (North Carolina Community College System, 2011). This crosswalk compared the two systems as follows:

- MAT 060: Equivalent to Modules 1-3 (DMA 010-030)
- MAT 070: Equivalent to Modules 4-6 (DMA 040-060), minus a few sections at the end of Module 6 that were originally in MAT 080.
- MAT 080: Equivalent to Modules 7-8 (DMA 070-080), plus the few sections at the end of Module 6.

The original MAT 050 course was originally delegated to non-credit continuing education courses, and thus was not included in the crosswalk. In Fall Semester of 2014, the MAT 050 course was re-introduced as a credit-bearing course at MCCC.

For the purposes of this study, the entire Module 6 material will be considered as part of MAT 080, which results in the following crosswalk:

- MAT 060 = DMA 010-030
- MAT 070 = DMA 040-050
- MAT 080 = DMA 060-080

There were also changes to the gateway math course pre-requisites. Most of the courses that required MAT 070 had their requirements change to needing only through

Modules 4 or 5 (meaning that, occasionally, a student needing MAT 070 under the old system may only need through Module 4 in the new system). Also, MAT 151 (Statistics I) had its pre-requisite changed to needing only through Module 5 (as opposed to through Module 8). The new pre-requisites for the gateway math courses are listed below (North Carolina Community College System, 2016c):

- MAT 115 (Mathematical Models) Pre-requisite: Through Module 5 (DMA 010-050)
- MAT 121 (Algebra/Trigonometry I) Pre-requisite: Through Module 5 (DMA 010-050)
- MAT 140 (Survey of Mathematics) Pre-requisite: Through Module 4 (DMA 010-040)
- MAT 151 (Statistics I) Pre-requisite: Through Module 5 (DMA 010-050)
- MAT 171/171A (Precalculus Algebra) Pre-requisite: Through Module 8 (DMA 010-080)

Also, the North Carolina Community College System (2016c) made changes to some of these gateway math courses in Fall Semester of 2014. MAT 140 (Survey of Mathematics) was retired and replaced at MCCC with MAT 143 (Quantitative Literacy), which required a math prerequisite through Module 5. As MCCC did not change its MAT 140 course to MAT 143 until Fall Semester of 2015 (past the timeframe of the study), this change will have no effect on study. MAT 151 (Statistics I) was also retired and replaced by MAT 152 (Statistical Methods I), with the same math prerequisite through Module 5. The only addition to these courses was a new requirement for completion of the developmental English sequence. As the developmental English sequence is beyond the specific scope of this study, it was not considered as part of this analysis.

The dataset used for this analysis consisted of the grade reports for all developmental mathematics courses and gateway mathematics courses taught at MCCC over the timeframe of the study (Fall Semester 2007 to Summer Semester 2015, as mentioned above), along with the aforementioned developmental mathematics module completion spreadsheets kept by the Mathematics Department of MCCC. Preliminary analysis suggested that this dataset should contain approximately 38,000 records (each record being a single student in a single course for a single semester), containing information on approximately 17,000 students. These records included a unique student identification number, which can be used to obtain demographic information on the student, such as race/ethnicity and gender. Students that enrolled in gateway math courses were also checked and marked as to their method of placement, either completing developmental courses, by placement test scores, by transferred course credits, or by the Multiple Measures for Placement policy (North Carolina Community College System, 2011). Once obtained, the student identification number was replaced with another proxy identification number (to preserve student anonymity) in preparation for analysis.

The students in the study were then divided into three groups, denoted “Old Cohort”, “New Cohort”, and “Mixed Cohort”. “Old Cohort” consisted of students who only enrolled in developmental math courses under the old developmental mathematics sequence (MAT 050, 060, 070, 080). “New Cohort” consisted of students who only enrolled in developmental math courses under the new developmental mathematics sequence (DMS 001, 002, 003, plus the re-implemented MAT 050). “Mixed Cohort” consisted of the students who enrolled in developmental courses in both sequences, such as those that were in the middle of their developmental math studies at the time that MCCC changed from the Old Cohort to the New Cohort. Students that placed into the gateway courses directly were placed into the “Old Cohort” group if their first gateway math course was before Fall Semester 2012, and into the “New Cohort” group if it was on or after Fall Semester 2012.

In these three groups, each student was placed in a state corresponding to the first developmental or gateway math course taken at MCCC. These states correspond to the course or module the student started in (under the old system, MAT 050, 060, 070, 080, 115, 121, 140, 151, 161, 171, under the new system, DMA 010, 020, 030, 040, 050, 060, 070, 080, MAT 050, 115, 121, 140, 151, 152, 171). The “Mixed Cohort” group used the New Cohort states, translating them from the Old Cohort states by use of the crosswalk given above. Four other states, “Withdrew from College”, “Passed Curriculum Math”, “Graduated Without Curriculum Math”, and “Still Enrolled”, were also included in the set of states.

These grade reports and module completion spreadsheets were then compiled together into transition records, denoting the proxy identification number, the semester, the course that student took (i.e. the current state for that student), and the new placement of the student based on the grade earned or modules completed in that semester (i.e. the state to which the student is transitioning). If a student did not pass a course or did not complete any modules, they were transitioned back into their current state. Students who passed their gateway course (with a “D” or better) were transitioned to a state labelled “Passed Curriculum Math”.

For the remaining students (who do not have a final state of "Passed Curriculum Math"), since it is possible to graduate with a certificate from MCCC without completing a curriculum-level math course, graduation records for these students (from the semester of their last course up until Summer Semester 2016) were checked to determine if a student graduated. Such students were transitioned from their last state to "Graduated Without Curriculum Math". Students who did not graduate were then be checked to see if they are still enrolled in at least one credit-bearing course at MCCC (for the semesters Fall 2015, Spring 2015, and Summer 2016). If so, they were transitioned to the "Still Enrolled" state, and if not, they were transitioned to "Withdrew from College".

Reduction of the Model and Testing of the Markov Property

As this analysis will be using a large number of statistical tests throughout, with a large sample size, there are valid concerns regarding the family-wide error rate of the study as well as the effect size of the findings. To address these concerns, the Sidak correction to the family-wide error rate was used to determine a value of significance to use for each test so that the family-wide error rate will be less than 0.05 for the entire study. Further, effect sizes for each test were calculated, and results where the effect size is less than 0.10 (often considered the benchmark for a "weak" effect size) were discounted.

The first analysis of the dataset was to attempt to reduce the number of states in each model. While the developmental courses cannot be reduced, some of the gateway courses are comparable (MAT 151 and MAT 152, and MAT 161 and MAT 171), with few differences in the material covered. As Markov chain models work best when the number of states is small, and the context and material that the courses cover are similar, pass rates for these courses were tested to determine if they can be combined to reduce the size of the transition matrix. Insignificance of the difference in pass rate for these course pairs was considered as sufficient evidence to combine the two states into one.

The second analysis was to confirm the Markov property. This requires testing three assertions for all of the students that enrolled in each of the courses in the developmental sequence.

1. The probability of passing a curriculum course is the same regardless of whether the student previously passed a curriculum mathematics course (Second Curriculum Math Course).
2. The probability of passing a course or completing a module or group of modules is the same for students taking the course for the first time and for students repeating the course (Course Attempts).
3. The probability of passing a course or completing a module or group of modules is the same for students placed directly into the course and for students transitioning to that course from a previous course in the sequence (Placement by Pre-requisite Course).

All three of these requirements were tested using either a standard two sample proportion Z-test (for course pass rates) or a t-test on the mean number of modules completed (for the new developmental mathematics modules). Insignificance at the appropriate level was considered as evidence of the fulfillment of that portion of the Markov property.

After these analyses have been performed, the dataset was recoded to correspond to the new states determined by these analyses, and testing on the research questions commenced.

Analysis of the Research Questions

As mentioned earlier, this study addressed the following research questions:

Research Question 1: Do students progress through their developmental mathematics sequence and through their chosen gateway mathematics course at a better rate in the new developmental mathematics sequence than in the old developmental mathematics sequence, given their initial placement?

For this question, three points where the two developmental mathematics sequences are comparable were defined, based on the crosswalk:

1. MAT 060 and DMA 010
2. MAT 070 and DMA 040
3. MAT 080 and DMA 060

Completion rates for the “Old Cohort”, “New Cohort”, and “Mixed Cohort” for students starting in those states were then compared, success being defined as passing the gateway math course (i.e. going to the state of “Passed Curriculum Math”). These were tested using a standard chi-square test of independence (using all four absorbing states) and also by a proportion Z-test (for the percentage of students going to “Passed Curriculum Math” over those students who end with the states “Passed Curriculum Math” or “Withdrew from College”). For all of these tests, the null hypothesis was that there is no significant difference in completion rates based on developmental math sequence.

Research Question 2: Do different student demographic variables (gender and race/ethnicity) have an effect on the progression rate through these two developmental mathematics sequences?

For this analysis, each of the three groups was separated by gender (male/female) and race/ethnicity (White, Black/African-American, Hispanic, and Other). Gender and race/ethnicity information for students was obtained from the student records system, and is based on information given at the time of application. While demographic categories (especially for gender) have expanded over the timeframe of the study, these expanded categories are not currently utilized in the standard application form for MCCC; therefore, gender and race/ethnicity categories for this study were restricted to those given above. Testing for these groups was done in the same fashion as for Research Question 1, using the same hypotheses (null hypothesis stating that there is no difference) and the same tests (chi-square test of independence followed by proportion Z-test on "Passed Curriculum Math" and "Withdrew from College"). Insignificance of the test was considered as evidence of no difference due to race/ethnicity and gender.

Research Question 3: Are there particular courses or modules in these two developmental mathematics sequences that have higher or lower rates of progression (pass or completion rates)?

For this research question, in the old developmental system, the pass rates of the developmental courses were analyzed to see if there are differences in the pass rates between the courses, using a standard proportion Z-test, with the null hypothesis of no difference in the pass rate of the courses.

For the new developmental system, the mean number of modules passed by each student (controlled by the number of modules selected) based on their starting module were calculated. These means were then compared using an analysis of variance test, with the null hypothesis of no difference in the mean number of modules passed based on the starting module.

Research Question 4: Do students placed directly into the gateway mathematics courses, particularly by the Multiple Measures method used by the North Carolina Community College System, complete the gateway course at similar rates than those that are placed into the gateway course by other methods (either by placement test or by completing developmental coursework)?

This question was answered using a test similar to the test from the preliminary analyses of pass rate in gateway math courses by placement method (developmental coursework, placement test scores, and Multiple Measures) described in the Reduction of the Model and Testing of the Markov Property section above. Student pass rates in each gateway course were tested using a proportion Z-test (comparing students placed by Multiple Measures to students placed by all other forms of placement), with the null hypothesis of no difference in pass rate by placement method. Insignificance of the test was taken as evidence of no difference by placement method.

Research Question 5: Does the crediting of completed modules (under the new developmental mathematics sequence) in a module shell course that the student failed (here called *partial credit*) have an effect on student progression, as opposed to the old developmental mathematics sequence, which had no option for partial credit?

This last analysis will be performed by comparing specific students from the "Old Cohort" group and the "New Cohort" group (the "Mixed Cohort" group was used for this analysis so as to avoid confounding effects caused by students taking courses in both sequences).

To get a comparable group of students for this analysis, care must be taken that the students are placed in identical spots (using the crosswalk given above, that would be MAT 060/Module 1, MAT 070/Module 4, and MAT 080/Module 6), and for the students in the new developmental mathematics sequence, that they are taking enough modules to be comparable to the old developmental mathematics sequence in terms of time in the classroom (i.e. three modules). This gives us the following students from the "New Cohort":

1. Students in Module 1 (DMA 010) taking three modules in a semester (the equivalent of the old MAT 060).
2. Students in Module 4 (DMA 040) taking three modules in a semester (the equivalent of the old MAT 070)
3. Students in Module 6 (DMA 060) taking three modules in a semester (the equivalent of the old MAT 080).

This specific cohort of "New Cohort" students was compared to the "Old Cohort" group directly, using the crosswalk given previously (DMA 010 = MAT 060, DMA 040 = MAT 070, DMA 060 = MAT 080). Two analyses were then performed. First, the pass rates of the courses were compared directly, counting only those students in the new developmental mathematics sequence who completed the required number of modules (3 or more for Module 1, 2 or more for Module 4, and 3 for Module 6) as passing the new developmental mathematics course, to simulate the effect of not allowing partial credit. In the second analysis, for the “Old Cohort” students, passing the course was counted as passing a number of modules based on the placement (again, for MAT 060, 3 modules, for MAT 070, 2 modules, and for MAT 080, 3 modules). Students in the “New Cohort” had their actual number of modules passed counted, with the provision that they will only be given credit up to the same number of modules as listed above for the “Old Cohort” students (so as to avoid issues with “New Cohort” students completing more modules than were available in an “Old Cohort” class). This second analysis would therefore account for the accumulation of partial credit under the new developmental mathematics sequence. The mean number of modules passed for both groups was then calculated and compared using a standard t-test, with the null hypothesis of no significant difference between the “Old Cohort” students and the “New Cohort” students.

Conclusion

Once these analyses were performed, the collective results of these research questions was compiled and a summary comparison of these two developmental mathematics sequences was composed. This summary noted any particular strengths and weaknesses of the sequences, paying particular attention to the effects of different type of students, different gateway courses, differences in transition probabilities and the effects of Multiple Measures and partial credit on student progression through the sequences. Limitations of the model and suggestions for further research were also considered.

CHAPTER 4: RESULTS

Description of the Dataset

The initial data set consisted of records for all developmental mathematics courses (for both the old developmental mathematics system and the new developmental mathematics system) and all curriculum mathematics courses at MCCC from Fall Semester 2007 to Summer Semester 2015, which consisted of 38,480 records (consisting of 1 record per mathematics course a student took at MCCC). Each record consisted of the student's name and identification number, the course name and number, along with the semester the course was taken and the grade earned. For each of these course records, the student's name and identification number was cross listed with the student's demographic information (to determine the student's ethnicity and gender) and with that student's academic and placement test scores (to determine course placement and possible transfer credit).

The student's grade in the course was also evaluated. For this study, grades of A-D for curriculum mathematics courses were considered as passing grades. For the old developmental courses, which were graded by either an A*, B*, C*, I* scale (where the A*, B*, and C* were similar to the A, B, and C grades and the I* grade was the equivalent of an F), or by the grades P and R (Pass or Repeat), passing grades were defined as A*, B*, and C* under the A*-I* system, and P under the P/R system.

During the timeframe of the study, as mentioned previously, there were college-wide changes in rules covering administrative withdrawal (the withdrawing of a student by a faculty member due to unsatisfactory progress in the course). Since this might result in a student receiving an F (Failing) grade for a course taken one semester and a W, WP, or WF (Withdraw, Withdraw Passing, or Withdraw Failing) for the same course in a different semester, all Withdraw grades (W, WP, and WF) were considered, along with F grades, as failing grades, so as to mitigate the effect of the changes in the administrative withdrawal policy.

For courses under the new developmental mathematics sequence, the student identification number and course number was checked against the MCCC Math Department's master list of completed modules. From this master list, the modules that the student completed (if any) were determined and variables created in the record denoting: (1) the number of modules the student chose to complete (based on the DMS numbering: DMS 001 = 1 module, DMS 002 = 2 modules, DMS 003 = 3 modules), (2) the module where the student started, (3) which modules were completed, (4) the next module that the student needed to complete (which determines the state to which the student transitioned after the course), and (5) the total number of modules completed in that course.

In determining the number of modules completed based on the MCCC Math Department's records, the following adjustments were made:

1. Many module completion sheets did not have module information for R or W grades where the student did not complete any modules in that course. For those courses, the student was marked as being at the next module to be completed if there were previous new developmental math coursework, or at Module 4 or 6 if there was completed old developmental coursework (completed MAT 060 and

MAT 070, respectively, in accordance with the crosswalk). If no previous coursework exists, the student was placed at the first required module based on placement test data and module course completion data from student transcripts.

2. For the first year of the new developmental system (Fall 2012-Summer 2013), the courses were coded as in the old developmental system (MAT 060, 070, and 080). If there were no previous new developmental coursework, the students in these courses were started at Modules 1, 4, and 6 respectively, in accordance with the crosswalk. Students were also given passing grades for the course based on the completion of the last module in the crosswalk for the MAT 060, 070, and 080 courses (Modules 3, 5, and 8, respectively). These have been recoded to module completions only (i.e. in the same way as the other new developmental mathematics courses), and the actual grades for the course have not been used in the analysis. For purposes of the number of modules chosen by the student, these courses were coded based on the number of modules needed by the student to complete the last module in the crosswalk, with exceptions as noted in #3 below.
3. Also in the first year of the new developmental system, students were required to complete a portion of Module 6 to qualify for MAT 140 and MAT 151. This portion of Module 6 (called Module 6A) covered all but the last 3 sections of the Module 6 material (sections 1-15 out of 18), but was not counted as a full completion of Module 6. This could cause a student to pass Modules 4 and 5 in a previous semester, complete only the Module 6A portion (which will be all they need to qualify for MAT 140 or 151), and therefore be successful in the course but have no completed modules. For the purposes of this analysis, they will be

counted as having chosen to complete 1 module and having completed module 6. This particular situation occurred only 5 times in the new developmental dataset (7,165 observations), and thus should not heavily influence the results of this study.

4. Some students skipped modules either while taking a new developmental math course, or between developmental math courses, mainly due to placement testing (the NCDAP placement test in particular). If this skipping of modules happened within a section, the number of modules completed and advanced were noted (skipped modules are counted as advanced, but not completed). If between sections, the student's placement test scores were consulted, and, if confirmed, the student was started in the appropriate module (with the skipped courses counted). If not confirmed, the student is noted in that course as a mis-assignment.
5. A few sections (5 sections) of new developmental math courses did not have module completion sheets. The results for these sections were re-created using the techniques described in #1 above.

Next, the records in the data set were reviewed for relevance to the research questions to be answered. Since course progression was to be determined by final grades, records containing no final grade or records with a final grade of credit by exam ("CE" grades) or audit ("AU" grades) were removed from the data set. Also, any curriculum mathematics course that had another curriculum mathematics course as a pre-requisite (such as MAT 272: Calculus II, which has a pre-requisite of another curriculum mathematics course, MAT 271: Calculus I) was removed from the data set, since the main focus of this study is on the progression of students through their first curriculum mathematics course.

For the records that remained, each record was given a placement method, which describes the method of placement that determined how a student fulfilled the pre-requisite requirements (if any) for that course. As there are multiple ways to fulfill these pre-requisites, but the research questions and model require only one, mutually exclusive placement for each record, a priority list was created for the placement methods. This priority list was based upon placing priority to local instruments or methods over more state-wide or national methods, putting placement by taking a pre-requisite course as the first valid (non-regressed) placement (for evaluating the Markov property), and with the new Multiple Measures method as the last valid placement, so as to allow an accurate testing of student success in curriculum courses based completely on the Multiple Measures criterion.

The placement priority list used for this study is given below:

Placement Order:

1. Regress: Student had placed into a higher level of math than the current course
2. Course: Student has successfully passed a pre-requisite math course at the institution
3. SAT/ACT: Student has an SAT Math Score of 500+, an ACT Math Score of 21+, or an ACT Composite Score of 21+ (which placed them out of all developmental coursework in math) within the last 5 years

4. Waiver/DMA Waiver: Student has a waiver out of all developmental coursework by some other method than SAT/ACT (such as having earned a bachelor's degree)
5. Placement Tests (NCDAP, Compass, CPT, Asset, Plan): Placed due to the results of a placement test (with priority order as listed above), using the highest placement among any of the tests. Satisfactory placement scores for each test and the appropriate placement are given below:
    a. NCDAP (each module): 7 or higher places a student out of that module
    b. Compass Pre-Algebra: 23 or higher placed a student in MAT 060/Module 1, 47 or higher places a student in MAT 070/Module 4/MAT 110
    c. Compass Algebra (assuming 47+ on Pre-Algebra): 46 or higher places a student in MAT 080/Module 6 or curriculum courses with a MAT 070/Module 4 or 5 pre-requisite (MAT 115, 120, 121, 140, 151), 66 or higher places a student in any curriculum course in this study
    d. CPT Arithmetic: 31 or higher places a student in MAT 060/Module 1, 55 or higher places a student in MAT 070/Module 4/MAT 110
    e. CPT Elementary Algebra (assuming 55+ on Arithmetic): 55 or higher places a student in MAT 080/Module 6 or any curriculum course with a MAT 070/Module 4 or 5 pre-requisite, 75 or higher places a student in any curriculum course in this study
    f. Asset Numeric: 34 or higher places a student in MAT 060/Module 1, 42 or higher places a student in MAT 070/Module 4/MAT 110

g. Asset Elementary Algebra (assuming 42+ on Numeric): 42 or higher places a student in MAT 080/Module 6 or any curriculum course with a MAT 070/Module 4 or 5 pre-requisite
h. Asset Intermediate Algebra (assuming 42+ on both Numeric and Elementary Algebra): 41 or higher places a student in any curriculum course in this study
i. Plan: 19 or higher places a student in any curriculum course in this study
j. If a student has placement scores, but none of those scores meet any of the criteria above, that student is placed at the lowest level (MAT 050 for both developmental sequences).

6. Transfer: Student has placement due to transfer courses from another institution
7. Multiple Measures: Multiple Measures waiver (as described in Chapter 1)
8. No Data: No placement data was available for the student
9. Misplaced: Incorrect placement

So, for example, if a student placed into a curriculum course by Multiple Measures and by having a Math SAT score of 520, that student would be listed as having placed by SAT/ACT, since SAT/ACT is higher on the priority list than Multiple Measures.

For the determination of the Regress placement, all placements (except for the Waiver placement, which is not always time-stamped) had a five-year lifespan (i.e. the shortest lifespan of any of the placement methods).

As there is sometimes a delay in getting certain placement methods entered into the system, placement by SAT/ACT, Waiver, or Multiple Measures were allowed up until the end on the semester of the course that the student was enrolled in. Placement test results are usually recorded faster than other scores, so those results were allowed if they were within seven days of the start of the course (to allow for the drop/add period and for data entry).

Also, a large number of legacy Placement Tests results (tests taken before the start of Fall 2007) were recorded on the implementation date of a new computer records system at MCCC (6/1/07) and have that date as the date of the test. These are treated in the model as actually having occurred on 6/1/07 for the purposes of the five-year lifespan.

Preliminary Analysis

After adding all of the necessary variables to the records, preliminary analysis on the data set was begun. This preliminary analysis was designed to determine if the number of states could be reduced, and to check the Markov property, specifically regarding course pass rates based on (1) having passed a curriculum mathematics course previously, (2) having taken, but not passed, the mathematics course in which they were enrolled, and (3) by passing a pre-requisite mathematics course.

As the study contains a large number of tests (225 tests total), and a large number of records, there are valid concerns that the large number of tests used may greatly inflate the family-wide error rate of the study, and that the large sample sizes involved may lead to statistically significant conclusion that have little actual effect. To address this, two adjustments to the standard statistical procedures will be made. First, the Sidak adjustment will be applied to the standard alpha value of 0.05, so as to ensure the family-wide error rate of all the tests (assuming independence) to 0.05. This new alpha value of approximately 0.00023 will be used for all tests in this study, and will necessitate that test statistics and p-values be calculated to five significant digits in most cases. Second, since the sample sizes for these tests are quite large in many cases, an effect size criterion of 0.10 (which denotes a borderline value of a “weak” effect for many measures of effect size) will be employed, so that, even if a test determines that a difference is statistically significant, it will be discounted unless its effect size exceeds 0.10.

Reduction of States.

As previously mentioned, two pairs of courses, MAT 151 (Statistics I) and MAT 152 (Statistical Methods I) and MAT 161 (College Algebra) and MAT 171/171A (Precalculus Algebra/Precalculus Algebra Lab) were sufficiently similar to each other in terms of course pre-requisites, material covered and desired student learning outcomes as to suggest that these course states could be combined in the model. To test this assertion, standard proportion Z-tests were performed comparing the pass rate of MAT 151 to MAT 152, and comparing the pass rate of MAT 161 to MAT 171 (MAT 171A had the same grades as MAT 171), as shown in Table 1 in the Appendix. Both of these tests were insignificant for the study’s alpha value:

MAT 151 vs. MAT 152, $Z = 1.80788$, $p = .07062$, ES = .03954

MAT 161 vs. MAT 171, $Z = -1.40188$, $p = .16095$, ES = .02140

Therefore, to make the model more parsimonious, the MAT 151 and MAT 152 courses will be combined together into one state (labelled MAT 151, since MAT 151 had the most observations of the two courses), and the MAT 161 and MAT 171/171A courses will also be combined together into one state (labelled MAT 161, since MAT161 had more observations).

Satisfaction of the Markov Property

Next, the data set was analyzed to determine if the Markov property was satisfied. For this study, three specific cases were analyzed:

1. Second Curriculum Math Course: Does a student who has already passed a curriculum mathematics course have a higher pass rate in another curriculum math course than a student who has not passed a curriculum mathematics course?
2. Course Attempts: Does a student who is attempting a mathematics course (curriculum or developmental) for the second or subsequent time have the same pass rate as a student attempting the course for the first time?
3. Placement by Pre-requisite Course: Does a student who places into a mathematics course (curriculum or developmental) by passing a pre-requisite course have the same pass rate as a student who placed in by other means (placement test, standardized test, Multiple Measures, etc.)?

Second Curriculum Math Course.

To answer the first question (regarding second curriculum math courses), all of the records in the data set were sorted in chronological order by semester, and any records of curriculum courses taken by a student after passing a curriculum mathematics course at MCCC were marked as "Subsequent". All of the remaining curriculum courses were marked as "First". Then, for each curriculum mathematics course, a proportion Z-test was performed comparing the pass rate of the "First" records against the "Subsequent" records, with the results given in Table 2 in the Appendix. Of the eight curriculum mathematics courses, one (MAT 151) had a significant difference in pass rate and a large enough effect size (MAT 151, First vs Subsequent: $Z = -4.60442$, $p < .00001$, ES = .10069) to fulfill the study's requirements. Therefore, students who pass a curriculum mathematics course in the past have a higher rate of passing MAT 151 than those who have not passed a curriculum mathematics course.

Since this finding would violate the Markov property (a past event affecting the pass rate of a current course), the model will need to be adjusted. As the main focus of the study is a student's progression through developmental mathematics to the first curriculum mathematics course, all of the "Subsequent" marked courses were removed from the data set, along with all developmental mathematics courses taken by students after they had passed a curriculum mathematics course. In addition, the academic records of all students were checked for the presence of a curriculum mathematics course earned by transfer credit, and, if found, all records after the assigned date of the transfer credit were removed. Once these course records were removed, the remaining records would then accurately track students who had not passed a curriculum mathematics course through the developmental sequences only until the point that they passed their first curriculum mathematics course, thereby avoiding the violation of the Markov property found in this result.

Course Attempts.

The next part of the preliminary analysis involved checking the Markov property for students based on the number of attempts the student had made for that course. To perform this test, the chronologically ordered data set was used, and each record was given a number denoting the ordinal number of that attempt of the same course (first attempt: Attempt = 1, second attempt: Attempt = 2, etc.).

Results for each course were first tested to determine if the first attempt (Attempt = 1) had different progression rates than subsequent attempts (Attempt > 1). For this analysis, the curriculum mathematics courses and the old developmental mathematics courses were compared by pass rates using proportion Z –tests (given in Table 3 for curriculum courses and in Table 4 for old developmental courses), and the new developmental mathematics courses were compared for students starting at the same module on mean number of modules completed by t-tests (given in Table 5).

For curriculum courses, both MAT 140 and MAT 161 had significant differences in pass rates fulfilling the requirements of the study:

MAT 140 First vs. Subsequent: $Z = 8.10199$, $p < .00001$, ES = .13937

MAT 161 First vs. Subsequent: $Z = 6.76314$, $p < .00001$, ES = .11638

For the old developmental courses, MAT 060, 070, and 080 were significant (with MAT 050 only slightly over the 0.00022 criterion), although the effect size for MAT 080 was slightly under the level needed for a “weak” effect:

MAT 050 First vs. Subsequent: $Z = 3.58370$, $p = .00034$, ES = .13402

MAT 060 First vs. Subsequent: $Z = 13.51623$, $p < .00001$, ES = .18280

MAT 070 First vs. Subsequent: $Z = 14.53938$, $p < .00001$, ES = .16002

MAT 080 First vs. Subsequent: $Z = 4.44785$, $p < .00001$, ES = .08290

Finally, for the new developmental courses, students starting at Module 4 and 6 had significantly higher mean number of modules completed based on the criteria of the study. Module 1 was also significantly different, although the effect size was slightly under the 0.10 required:

Module 1 First vs. Subsequent: $t(2553) = 4.29683$, $p < .00001$, ES = .08501

Module 4 First vs. Subsequent: $t(2403) = 8.70317$, $p < .00001$, ES = 17747

Module 6 First vs. Subsequent: $t(798) = 5.46183$, $p < .00001$, ES = .19310

Based on these results, it is clear that for a significant number of courses or states, subsequent attempts do not have the same pass rate as the first attempt. Therefore, a repeat state (denoted with a –R) was created for each state, and students who did not progress from a course and later attempted that course again were, for the first attempt, transitioned to the repeat state. For example, if a student attempted MAT 070 for the first time and did not pass, they would be transitioned to the state MAT 070-R.

Next, similar comparisons for all of the courses were made comparing the second attempt (Attempt = 2) at a course to the third or higher order attempts (Attempt > 2), using the same statistical tests as before. The results of these tests are given in Table 6 for curriculum courses, Table 7 for old developmental courses, and Table 8 for new developmental courses. Sample sizes for these tests dropped dramatically, with a few courses failing to meet the sample size requirements for the test. Of those that did have a sufficient sample size, none met the criteria for significance and effect size for this study. This means that there is no significant difference in progression between the second and subsequent attempts, and that no further repeat states need to be added to the model for subsequent attempts.

Effect of Previous Repeats on Subsequent Course Pass Rates.

However, the creation of the "-R" repeat states creates another issue with the model, namely, how to transition students from repeat states. For example, assume that, under the old developmental sequence, a student attempts MAT 060 for the first time and fails to pass the course. This student would then be transitioned to the MAT 060-R state (as described above). Then, on their second attempt, the student passes MAT 060, and should, therefore, be transitioned to MAT 070. However, there are two MAT 070 states, MAT 070 and MAT 070-R. To which of these states should the student be transitioned?

To address this question, each record in the chronological list was given a value based on whether the student had repeated a previous, lower-level course due to not passing that course. If the student had not repeated a course previously, the value of this new variable (HasRepeat) was set to 0. Once a student had repeated a course due to not passing it previously, the variable HasRepeat was set to 1 for all subsequent, higher-level courses.

All of the math courses (with the exception of MAT 050, which, since it is the lowest level course, cannot have HasRepeat = 1) were tested using the same tests in the attempts tests above, comparing those students without previous repeats (HasRepeat = 0) to those with previous repeats (HasRepeat = 1). The results of these tests are given in Tables 9 (for curriculum courses), 10 (for old developmental courses) and 11 (for new developmental courses).

Summarizing from all three tables above, several courses or states had significant differences and effect sizes (under this study's criteria) based on previous repeats, with others coming very close:

MAT 140: HasRepeat 0 vs. 1: $Z = 5.53804$, $p < .00001$, ES = .09635

MAT 060: HasRepeat 0 vs. 1: $Z = 6.23640$, $p < .00001$, ES = .08435

MAT 070: HasRepeat 0 vs. 1: $Z = 12.30026$, $p < .00001$, ES = .13537

MAT 080: HasRepeat 0 vs. 1: $Z = 8.36111$, $p < .00001$, ES = .15583

Module 4: HasRepeat 0 vs. 1: $t(2403) = 7.38810$, $p < .00001$, ES = .15065

Module 5: HasRepeat 0 vs. 1: $t(386) = 4.79576$, $p < .00001$, ES = .24347

Module 6: HasRepeat 0 vs. 1: $t(798) = 3.92354$, $p = .00005$, ES = .13872

Based on the results of these analyses, it appears that, in many cases, a previous repeat stays with a student even after completion of the course that they needed to repeat, lowering their pass rate in all subsequent courses (and, in some cases, by a statistically significant amount). While it is possible to add even more states to the model to account for previous repeats (for example, creating "-PR" states, for Previous Repeat), sample size issues and the size of the transition matrix (adding an extra 19 states for all 20 courses except MAT 050 would end up adding 2,033 additional transition probabilities to the final model) suggest that the model be kept as simple as possible Therefore, for the purposes of model parsimony, students who progress from a repeat ("-R") state will be transition to the next state's repeat state (i.e. a student in MAT 060-R who passes MAT 060 will transition to MAT 070-R).

Placement by Pre-requisite Course.

The final check of the Markov property was to determine if student who were placed into a course or module by completing previous courses or modules had similar progression rates as students who placed into that course or module by other methods. To test this, the data set was divided into two groups, "Course", for those students who had a placement of "Course" using the Placement priority list described above, and "Other", for any other placement. These two groups were compared using a proportion Z-Test on course pass rates for the curriculum mathematics states (that is, for each course, the non-repeat state and the repeat state were evaluated separately, due to the findings on progression by attempts given above) and for the old developmental mathematics states (excluding MAT 050, which has no pre-requisite course), and as t-test on mean number of modules (by modules chosen and starting module) completed for the new developmental mathematics sequence states.

The results are given in Table 12 for the curriculum mathematics courses, Table 13 for the old developmental mathematics courses, and Table 14 for the new developmental mathematics modules. Many of the tests, particularly for the new developmental mathematics module states had very small sample sizes, either making the test impossible to calculate (having a sample size of 1 makes standard deviation impossible to calculate) or making a lot of the conclusions suspect. Therefore, for reporting purposes, only significant results where the sample size is larger than 10 for both samples will be reported.

The following states had significant differences (or close to significant) and had sufficient sample sizes and effect sizes on the Course vs. Other placement tests to satisfy the study criteria (samples sizes are given with Course sample size first, then Other):

MAT 161-R (n, 100 v 23): $Z = 3.82387$, $p = .00013$, ES = .16883

MAT 070 (n, 2078 v 3705): $Z = -6.35189$, $p < .00001$, ES = .08353

Module 4, Chose 2 (n, 199 v 186): $t(383) = -2.43365$, $p = .00770$, ES = .12403

Module 4, Chose 3 (n, 387 v 806): $t(1191) = -2.62951$, $p = .00433$, ES = .07613

The test for MAT 161-R is the only one of the tests that satisfies all of the criteria, and has a sample size for Other placement that is a little small. The other tests of interest are those for MAT 070/Module 4. While none of these fit all of the criteria for the study, it is apparent that this subject matter (beginning algebra, covered by both MAT 070 and by Modules 4 and 5, which would be in both Module 4, Chose 2 and Module 4, Chose 3 groups) may be an area of concern for student progression. However, since only 1 test (MAT 161-R) out of 68 total fulfilled all of the criteria in the study for a difference in progression rate, we will proceed with concluding that, with cautions about MAT 161-R and the MAT 070/Module 4 states, placement by passing a pre-requisite course does not, in general, lead to different progression rates in a subsequent course or module.

Analysis of the Research Questions

After completion of the preliminary analysis, as mentioned above, records for mathematics courses taken after a student had passed a curriculum mathematics course were removed from the data set. This finalized the data set that will be used to answer the research questions, comprising 34,373 records on 15,790 students. Overall demographic information for the finalized data set was also calculated, and is given in Table 15. The results for the finalized data set (60% female, 40% male; 65% White, 25% Black/African-American, 5% Hispanic, 5% Other) is fairly comparable to the demographic percentages for MCCC students as a whole (given in Chapter 3), with only a 5 percentage point change in White and Black/African-American.

To assist in analyzing the research questions relating to a student's final results (i.e., the absorbing states), another data set was created to classify each student's final results. This data set consisted of a single record per student, and recorded that student's identification number, name, cohort (old, new, or mixed), starting state (the first class/state the student took at MCCC), the placement method of that starting state (using the placement priority list above), if the student did or did not have a repeat status somewhere in their developmental courses, the last course or module that the student took at MCCC, and the progression status (pass/fail or last module completed) of the last course or module. The student identification numbers in the study were also cross-referenced to graduation records for the timeframe of the study and with current enrollment records for the Fall 2015-Summer 2016 academic year at MCCC.

Based on these results a final status for each student was determined based on the following priority list:

1. Passed Curriculum Mathematics Course (“Passed”): Student’s last course was a curriculum mathematics course and the student passed that course.
2. Graduated Without Curriculum Mathematics: Some programs at MCCC (particularly certificate programs) allow a student to graduate with a credential without having to complete a curriculum mathematics course. Therefore, it is possible for a student to be in a program that requires a curriculum mathematics course, start in developmental mathematics (under either system), decide that the current program they are in does not suit their purposes and change their program to one that does not require a curriculum mathematics course, leaving the developmental mathematics sequence in the process (since it is no longer necessary). This would lead to the model classifying the student as not having completed a curriculum mathematics course when their revised goal (after changing programs) does not require them to complete a curriculum mathematics course. To account for this possibility, students who did not complete a curriculum mathematics course are checked against the list of students who graduated from MCCC over the time period of the study. If a student graduates from MCCC (under any program) during or after the semester in which they took

their last course or module, they are classified as “Graduated Without Curriculum Mathematics”, so as to avoid these issues.

3. Still Enrolled: Of the students that remain, if they were enrolled in at least one credit-bearing course at MCCC during the Fall 2015-Summer 2016 academic year, they are classified as “Still Enrolled”.
4. Did Not Pass Curriculum Math: All of the remaining students are classified as “Did Not Pass Curriculum Math”.

At this point, since personally identifiable student information was no longer needed, proxy identification numbers were created for each student and the student’s actual student identification number, along with the student’s name, was removed from both of the data sets. Both data sets were then used to analyze the study’s research questions, as given below.

Research Question 1: Do students progress through their developmental mathematics sequence and through their chosen gateway mathematics course at a better rate in the new developmental mathematics sequence than in the old developmental mathematics sequence, given their initial placement?

Analysis Results.

To analyze this research question, the final status data set was analyzed, dividing students into different placement groups and comparing students by cohort. As this analysis controls for placement, accurate placement of students is important, so students whose placement into their starting course was classified as “Misplaced,” “Regress,” or “No Data” were removed from the data set for this analysis. For purposes of placement, the following categories were defined:

- MAT 050
- MAT 060/Modules 1-3
- MAT 070/Modules 4-5
- MAT 080/Modules 6-8
- Curriculum (Pre-req 060): Started in a curriculum course with a pre-requisite of MAT 060 or a final module pre-requisite of Modules 1-3. This consists of only the MAT 110 course
- Curriculum (Pre-req 070): Started in a curriculum course with a pre-requisite of MAT 070 or a final module pre-requisite of Modules 4-5. This consists of the MAT 115, MAT 120, MAT 121, MAT 140, and MAT 151 courses.
- Curriculum (Pre-req 080): Started in a curriculum course with a pre-requisite of MAT 080 or a final module pre-requisite of Modules 6-8. This consists of the MAT 161 and MAT 175 courses.

First, the cohorts were tested, by placement, for the distribution of final states using a chi-squared test of independence. In addition, a follow-up proportion Z-test was performed comparing the curriculum pass rates of each cohort, considering only those students who were classified as "Passed Curriculum Math" and "Did Not Pass Curriculum Math". The results of this analysis is given in Table 16 (for the chi-square tests) and Table 17 (for the proportion Z-tests).

All placements showed significant differences in final status distribution for all placements, however, a lot of that difference can be explained by the "Graduated Without Curriculum Math" category and the "Still Enrolled" category (students from the new developmental system, being more recent, are more likely to still be enrolled at MCCC).

Therefore, the rest of the discussion will be based primarily on the proportion Z-tests for students classified as "Passed Curriculum Math" and "Did Not Pass Curriculum Math".

The mixed cohort had some small sample sizes (often falling under the required expected value of 5 per cell for the chi-square test of independence), but, overall, the mixed cohort had significantly better results than both the old and the new cohorts for students placed in MAT 060/Module 1-3, as shown in the proportion Z-tests:

MAT 060 Placement Old vs. Mixed: $Z = -3.84822$, $p = .00012$, ES =.06488

MAT 060 Placement New vs. Mixed: $Z = -5.46839$, $p < .00001$, ES = .12464

The mixed cohort had insignificant differences at the other developmental placements (MAT 050, MAT 070/Module 4-5, and MAT 080/Module 6-8). Since the mixed cohort requires having taken both sequences of developmental mathematics, placement at the curriculum level is not possible for the mixed method cohort.

As for comparisons of the old and new cohorts, the old cohort had a higher pass rate than the new cohort for all placements. Although none of the tests met the criteria set in the study, some were very close (Pass rates for each cohort in parentheses):

MAT 050 (Old 4.6%, New 0.0%): $Z = 1.25641$, $p = .20897$, ES = .06251

MAT 060 (Old 13.0%, New 10.0%): $Z = 2.93163$, $p = .00337$, ES = .04297

MAT 070 (Old 33.8%, New 27.4%): $Z = 3.62437$, $p = .00029$, ES = .05392

MAT 080 (Old 52.6%, New 42.7%): $Z = 2.23242$, $p = .02559$, ES = .07829

Curr (Pre-req 070) (Old 84.8%, New 79.1%): $Z = 2.79619$, $p = .00517$, ES = .07144

Curr (Pre-req 080) (Old 81.8%, New 80.3%): $Z = 0.77684$, $p = .43725$, ES = .01950

The Curriculum (Pre-requisite 060) only contains the course MAT 110, which started when the new developmental mathematics sequence was already implemented, therefore, there were no data for the old cohort for Curriculum (Pre-requisite 060).

It would appear at first glance that the old developmental mathematics system was marginally better for students than the new system, in particular for students placing into MAT 060 and MAT 070 (in the new system, Modules 1-3 and Modules 4-5), or in curriculum courses with a pre-requisite of MAT 070, all of which came close to meeting the significance level of the study. There are, however, other factors that may be influencing these results, so some further analyses were performed.

Start State by Cohort.

Although the previous analysis separated the students in each cohort by placement, it is worth investigating if there is any difference in the distribution of placement across the cohorts. A comparison of the starting placement of students by cohort, along with chi-square tests, is given in Table 18.

Of note in this comparison is the high number of students in the new cohort who place directly into curriculum courses with a pre-requisite of MAT 080/Modules 6-8 (New: 19.4% vs. Old: 7.4%). MCCC has become a more transfer-oriented institution over the time frame of the study, and this result may be a part of that shift, along with the Multiple Measures placement. If students placed into curriculum courses with lower pre-requisites are moved to the appropriate developmental course level (moving Curriculum Pre-requisite 060 students to MAT 070/Module 4-5 and Curriculum Pre-requisite 070 students to MAT 080/Module 6-8, which would, in effect, force all students to be placed according to the full developmental sequence), we also see a higher percentage of students placed at the MAT 060/Module 1-3 level (New: 41.3% vs. Old: 33.3%). The chi-square test does show a very significant distributional difference between the old and new cohorts ($\chi^2(4) = 814.48034$, $p < .00001$, ES = .26941), so it would appear that the new developmental sequence students have a more bimodal distribution as compared to the old developmental sequence students.

Comparison of Curriculum Course Passed by Pre-requisite, by Cohort.

The first additional analysis involved comparing which curriculum courses were passed for each cohort by that curriculum course's pre-requisite. This was done to determine if some cohorts were attempting and passing the higher-level curriculum courses, which might lead to a difference in curriculum pass rate. While it is impossible to completely determine a developmental student's intention on an eventual curriculum mathematics course if the student never progresses to the point of enrolling in that course, we can analyze those students that passed a curriculum course to get some indication of any differences in selected curriculum course distribution. The results of this analysis are given in Table 19.

From this table, it is clearly evident that the new cohort has a higher percentage of students that pass curriculum courses with a pre-requisite of MAT 080/Modules 6-8 than the other two cohorts (New: 49.6% as compared to Old: 34.4% and Mixed: 20.5%). The old and mixed student cohorts tend to select and pass curriculum courses with a pre-requisite of MAT 070/Modules 4-5 (New: 47.4%, Old: 65.5%, Mixed: 75.3%). This would lead to the conclusion that students in the new developmental mathematics sequence are staying in the developmental sequence longer (to get to the higher pre-requisite curriculum courses), which may explain the lower pass rates.

While the analysis above does suggest that students in the new developmental sequence who pass a curriculum mathematics course tend to stay in the developmental sequence longer, it does not control for placement and does not account for students who did not progress to, or did not pass, the curriculum mathematics course. So, to investigate this further, the final states of students classified as “Passed Curriculum Math” and “Did Not Pass Curriculum Math” were modified to convey more information. The new classification of the final state for these students would show the last state that the student was in the sequence, either as a developmental course or module, or, for those students that progressed to a curriculum course but did not pass it, the pre-requisite level of that last curriculum course. The categories for this new classification were as follows:

- MAT 050
- MAT 060/Modules 1-3
- MAT 070/Modules 4-5
- Failed Curriculum Course (Pre-req 060)
- MAT 080/Modules 6-8
- Failed Curriculum Course (Pre-req 070)
- Completed Developmental, but No Curriculum Course Taken
- Failed Curriculum Course (Pre-req 080)
- Passed Curriculum Course (Pre-req 060)
- Passed Curriculum Course (Pre-req 070)
- Passed Curriculum Course (Pre-req 080)

The full table of final states by start state and cohort is given in Table 20.

Cell sizes would be too small to attempt a chi-square test of independence for this data, however, investigation into the distribution of students by start state and cohort does show some illuminating results in the categories of MAT 080/Module 6-8, Fail Curriculum (Pre-req 070) and Pass Curriculum (Pre-req 070). For the old and new cohorts, we find the following:

Placement: MAT 060/Module 1-3:

Cohort	MAT 080/Module 6-8	Fail Curr 070	Pass Curr 070
Old	97 (3.1%)	69 (2.2%)	339 (10.9%)
New	128 (8.4%)	33 (2.2%)	108 (7.1%)

Placement: MAT 070/Module 4-5:

Cohort	MAT 080/Module 6-8	Fail Curr 070	Pass Curr 070
Old	348 (9.6%)	119 (3.3%)	939 (25.9%)
New	245 (27.6%)	28 (3.1%)	174 (19.6%)

From these results, it is apparent that there is a larger percentage of students in the new cohort that continue on into MAT 080/Module 6-8 than did in the old cohort, and those students often do not progress out of MAT 080/Module 6-8.

Curriculum Mathematics Completion and Repeat States.

One of the key findings in the preliminary analysis is the drop in progression rates if a student has to repeat a course, and that drop in progression rates stays with a student even after they complete the course they had to repeat. Therefore, another factor to consider regarding the comparison of student progression under the old and new developmental sequences is how these sequences affect course repeats. To do this, a proportion Z-test was performed on the percentage of students in the old and new cohorts who had at least one repeat (the mixed cohort, by its nature, is more likely to have repeats and was therefore excluded from this analysis). The results of this analysis are given in Table 21. From this table, it is clear that the new cohort students are less likely to have a repeat than the old cohort students (New: 10.2% had a repeat vs. Old: 21.1%, $Z = -16.57523$, $p < .00001$, ES = .13550).

Next, we investigate if students who have a repeat have a lower chance of passing a curriculum mathematics course. This analysis is given in Table 22. For both the new and the old cohorts, the students without a repeat had a higher rate of passing their first curriculum mathematics course than the students with a repeat; however, the effect sizes were rather small:

New Cohort (No Repeat 40.4% vs. Repeat 29.4%): $Z = 4.21957$, $p < .00001$, ES = .06676

Old Cohort (No Repeat 38.5% vs. Repeat 27.9%): $Z = 8.82934$, $p < .00001$, ES = .09041

Therefore, students who have a repeat have about a 10 percentage point lower chance to complete a curriculum mathematics course than students without a repeat, and students in the new developmental mathematics sequence have a lower chance to repeat a course or module than those in the old developmental mathematics sequence.

Research Question 2: Do different student demographic variables (gender and race/ethnicity) have an effect on the progression rate through these two developmental mathematics sequences?

Analysis Details.

For this research question, the same initial analysis of starting state and final status (using the 4 categories of “Passed Curriculum Math”, “Graduated Without Curriculum Math”, “Still Enrolled”, and “Did Not Pass Curriculum Math”) by cohort and placement done for Research Question 1 were performed, this time dividing the groups by gender (Female and Male) and by ethnicity (using 4 categories due to sample size: White, Black/African-American, Hispanic, and Other). Since the sample sizes would be too small for analysis, the other analyses performed in Research Question 1 were not performed on gender and ethnicity.

Comparison by Gender.

First, the starting placement of students by cohort and gender was analyzed, with the results given in Table 23. From the results, we note that, for all three cohorts, female students are more likely to be placed lower (using the combined categories where students placed in a curriculum course with a pre-requisite of MAT 060 are put in MAT 070/Module 4-5, and students placed in a curriculum course with a pre-requisite of MAT 070 are put in MAT 080/Module 6-8):

<u>Cohort: Mixed</u>

Gender	MAT 060/Mod 1-3	MAT 070/Mod 4-5	MAT 080/Mod 6-8
Female	338 (61.7%)	169 (30.8%)	8 (1.5%)
Male	124 (44.4%)	128 (45.9%)	10 (3.6%)

Cohort: New

Gender	MAT 060/Mod 1-3	MAT 070/Mod 4-5	MAT 080/Mod 6-8
Female	1,378 (46.9%)	607 (20.7%)	412 (14.0%)
Male	701 (34.6%)	512 (25.3%)	360 (17.8%)

Cohort: Old

Gender	MAT 060/Mod 1-3	MAT 070/Mod 4-5	MAT 080/Mod 6-8
Female	2,181 (39.2%)	2,146 (36.0%)	985 (16.5%)
Male	1,138 (28.3%)	1,679 (41.8%)	720 (17.9%)

All three chi-square tests for independence were significant, with effect sizes from .09 to .18. It would, therefore, appear that female students are more likely to be initially placed lower in all three cohorts.

Next, we analyze the final status of students by cohort, placement, and gender, which is given in Table 24 (for the chi-square tests) and Table 25 (for the proportion Z-tests). Here, we see a few differences in distribution (as evidenced by the chi-square tests), but these may be attributed to the "Graduated Without Curriculum Mathematics" group (males appear to be more likely than females to fall in that category). Then, looking at the proportion Z-tests comparing "Passed Curriculum Math" to "Did Not Pass Curriculum Math", none of the tests met the significance level for this study (although the old cohort of students placed into MAT 070/Module 4-5 came close: $Z = -3.34423$, $p = .00083$, ES = .05559). Therefore, once placement has been considered, females have similar progression rates as males in all three cohorts.

Comparison by Ethnicity.

To answer the research question regarding ethnicity, we again consider first any differences in initial student placement. The results of this analysis are given in Table 26.

All of the chi-square tests for independence were significant and had a sufficiently large effect size, so the investigation will continue to a more detailed analysis of exactly where the difference in distribution occurs. Student who identified as Hispanic or Other often had low sample sizes, but, where the sample sizes were sufficient for analysis, had comparable distributions to Whites, so we will focus on the differences between students identifying as White and those identifying as Black/African-American. Again, we will note the percentage of students falling into each placement category (using the same grouping as done for the gender analysis above):

Cohort: Mixed

Ethnicity	MAT 060/Mod 1-3	MAT 070/Mod 4-5	MAT 080/Mod 6-8
White	236 (50.5%)	201 (43.0%)	10 (2.1%)
Black/AA	181 (65.6%)	64 (23.2%)	2 (0.7%)

Cohort: New

Ethnicity	MAT 060/Mod 1-3	MAT 070/Mod 4-5	MAT 080/Mod 6-8
White	1,042 (34.6%)	760 (25.2%)	549 (18.2%)
Black/AA	761 (62.7%)	211 (17.4%)	103 (8.5%)

Cohort: Old

Ethnicity	MAT 060/Mod 1-3	MAT 070/Mod 4-5	MAT 080/Mod 6-8
White	1,845 (27.2%)	2,885 (42.6%)	1,290 (19.0%)
Black/AA	1,200 (50.5%)	627 (26.4%)	273 (11.5%)

From this analysis, it appears that Black/African-American students are more likely to be placed lower than White (and Hispanic and Other) students in all three cohorts.

Next, we use the same progression analysis for ethnicity as we used above for gender. The results of this analysis are given in Table 27 (for the chi-square tests) and Table 28 (for the proportion Z-tests). Again, sample size concerns make analysis of Hispanic and Other students problematic, so the study will focus on the proportion Z-tests for White students vs. Black/African-American students. Where there are sufficient sample sizes for analysis, Black/African-American students pass at a lower rate on almost all combinations of cohort and placement, with some tests coming close to the criteria set forth for the study (Pass percentage by group, placement, and cohort in parentheses):

<u>Placement: MAT 060/Module 1-3</u>:

Mixed Cohort (White, 24.1% vs. AA, 11.9%): $Z = 2.90228$, $p = .00371$, ES = .15425

New Cohort (White, 12.4% vs. AA, 6.9%): $Z = 3.29568$, $p = .00098$, ES = .08993

Old Cohort (White, 14.4% vs. AA, 9.4%): $Z = 3.97689$, $p < .00001$, ES = .07440

<u>Placement: MAT 070/Module 4-5</u>:

Mixed Cohort (White, 32.3% vs. AA, 27.3%): $Z = 0.69966$, $p = .48414$, ES = .04728

New Cohort (White, 29.5% vs. AA, 17.0%): $Z = 3.27590$, $p = .00105$, ES = .11722

Old Cohort (White, 36.1% vs. AA, 24.6%): $Z = 5.40463$, $p < .00001$, ES = .093799

Placement: MAT 080/Module 6-8:

Mixed Cohort: Insufficient Sample Size (White: n = 9, AA: n = 2)

New Cohort (White, 43.9% vs. AA, 37.5%): $Z = 0.57504$, $p = .56527$, ES = .05024

Old Cohort (White, 54.9% vs. AA, 40.0%): $Z = 2.77084$, $p = .00559$, ES = .11340

Based on the results of this analysis, it appears that Black/African-American students have a lower chance of passing a curriculum mathematics course (controlling for placement) than White students, across all three cohorts. This is particularly true for Black/African-American students placed in the lowest levels of developmental mathematics (MAT 060/Modules 1-3 and MAT 070/Modules 4-5).

Research Question 3: Are there particular courses or modules in these two developmental mathematics sequences that have higher or lower rates of progression (pass or completion rates)?

Analysis Results.

For this question, we will compare the pass rates of the old developmental courses directly, while we will compare the mean number of modules passed using ANOVA tests for the new developmental modules. With the new developmental modules, since the number of modules a student chose to complete in a semester affects the amount of time in the course, which would affect the number of modules completed, we will control for the number of modules chosen by only comparing students who chose the same number of modules (regardless of starting module). Since we noted a difference in progression rates due to repeats, we will again control for that in this analysis by separating students into the No Repeat and Repeat states (blank and "-R").

For the old developmental courses, the pass rates for those courses will be used in the analysis of Research Question 5, and the results of that analysis are given in Table 33. A brief summary of the pass rates is given here:

Course/State	# Passed	# Did Not Pass	Pass %
MAT 060	2,444	2,109	53.7%
MAT 060-R	266	648	29.1%
MAT 070	3,511	2,902	54.7%
MAT 070-R	608	1,235	33.0%
MAT 080	1,040	1,076	49.1%
MAT 080-R	249	514	32.6%

The old developmental courses appear to have a fairly steady pass rate of around 50% for the non-repeat students, and around 30% for the repeat students.

Details of the analysis of the mean number of modules passed by start state and repeat is given in Table 29. The ANOVA test was insignificant for those students choosing one module, but the ANOVA test did have some significant differences for students who chose 2 or 3 modules. For a post-hoc test, the Tukey's HSD test (applied only to the students who chose 2 or 3 modules, and with 99.9% confidence due to family-wide error rate concerns) noted some significant differences (where $p < .0002$) for mean module completions (as listed in Table 30), with Modules 1 and 7 being the module start points that had the highest mean number of completions, and Modules 2 and 6 having the lowest mean number of modules completions.

Research Question 4: Do students placed directly into the gateway mathematics courses, particularly by the Multiple Measures method used by the North Carolina Community

College System, complete the gateway course at similar rates than those that are placed into the gateway course by other methods (either by placement test or by completing developmental coursework)?

Analysis Results.

For this analysis, students taking curriculum mathematics courses will be classified as either "MM", for those placed by Multiple Measures, or "Other" for those placed by other means. The comparison of pass rates for those curriculum courses, based on students being placed by Multiple Measures or some other method is given in Table 31.

From the table, we note that all of the tests were insignificant except for MAT 161, which had multiple measures students passing at significantly lower rates (MM vs. Other, $Z = -6.65682$, $p < .00001$, ES = .12361). Since these results could be affected by repeats, the same analysis was performed using only each student's first attempt, the details of which are given in Table 32. Here, again, Multiple Measures students had significantly lower pass rates in MAT 161 (MM vs. Other, $Z = -6.65960$, $p < .00001$, ES = .13081), but not in any other courses. Since MAT 175 was removed before the implementation of Multiple Measures, the MAT 161 course is, therefore, the only curriculum course analyzed in this study that requires a pre-requisite of all developmental courses or modules (MAT 080/Modules 6-8), and is also the only course that Multiple Measures students pass at a lower rate, which would suggest that Multiple Measures (in its current form) may be a sufficient condition for a student to be ready for a course with a pre-requisite of MAT 070/Module 4-5 (such as MAT 140 or MAT 151), but not for MAT 161.

Research Question 5: Does the crediting of completed modules (under the new developmental mathematics sequence) in a module shell course that the student failed (here called *partial credit*) have an effect on student progression, as opposed to the old developmental mathematics sequence, which had no option for partial credit?

Analysis Results.

For this research question, the student results for the old developmental courses were re-coded into the new developmental module system to allow for comparison. Under this re-coding, passing MAT 060 was re-coded as a student progressing from Module 1 to Module 4 (the start of MAT 070), thus passing 3 modules, passing MAT 070 was re-coded as a student progressing from Module 4 to Module 6 (the start of MAT 080), thus passing 2 modules, and passing MAT 080 was re-coded as a student progressing from Module 6 through Module 8, thus passing 3 modules. Not passing these courses was treated as a transition from the starting module state (Module 1 for MAT 060, Module 4 for MAT 070, and Module 6 for MAT 080) back to that same state.

Since students can choose the number of modules they need to complete to pass the course, and thereby choose how much time they spend in class (as detailed previously), it is important that the students spend the same amount of time in the classroom under the new system as they did under the old developmental system, or at least as close as is possible. Students choosing 3 modules to complete have the most comparable amount of time in the classroom under the new developmental system, so the analysis only used students under the new system that chose to complete 3 modules, and started at Module 1, 4 or 6 (the comparable points to MAT 060, MAT 070, and MAT 080).

Also, since students under the new developmental mathematics sequence could possibly complete more modules than would be comparable to the material covered by the old developmental courses, students in the new developmental mathematics sequence had the number of completed modules truncated to only the number of modules covered by the old developmental course to which they are being compared (for MAT 060/Module 1, truncated to passing a maximum of 3 modules, for MAT 070/Module 4-5, 2 modules, and for MAT 080/Module 6-8, 3 modules).

Under these modifications, the old and new developmental sequences was compared using pass rates (pass rates under the old developmental sequence versus maximum module pass rates under the new developmental sequence) and mean number of modules completed (counting completed old developmental courses as a number of completed modules as detailed above). The pass rate analysis does not allow for any partial credit accumulation (not passing the required amount of modules is the equivalent of failing), but the mean number of modules completed will allow for partial credit, so differences in the results of these analyses would tend to be attributable to partial credit. Again, as repeats affect pass and progression rates, the data was divided into Non-Repeat and Repeat states as before. The results of this analysis are given in Table 33 (for progression percentages) and Table 34 (for mean number of modules passed).

Below is a comparison of pass rates for the old developmental sequence as compared to comparable module completion rates for the new developmental sequence (from Table 32):

Course/State	Pass Rate (Old)	Complete All Modules (New)
MAT 060	53.7%	40.2%
MAT 060-R	29.1%	32.4%
MAT 070	54.7%	54.9%
MAT 070-R	33.0%	38.0%
MAT 080	49.1%	40.8%
MAT 080-R	32.6%	19.4%

The old developmental sequence courses appear to have higher pass rates than the comparable rates for the new developmental sequence for MAT 060 and MAT 080/MAT 080-R, while the new developmental sequence has higher rates for MAT 060-R and MAT 070-R. The MAT 070 state appears to be about the same for both sequences. Note that these results do not account for accumulation of any partial credit.

Next, a comparison of the average number of modules completed was performed, which will account for partial credit. From the results on Table 33, the new developmental sequence has a higher mean number of modules completed than the old developmental sequence, and significantly higher for the MAT 060 and MAT 070 states:

Course/State	Old	New
MAT 060	1.610	1.769
MAT 060-R	0.873	1.505
MAT 070	1.095	1.252
MAT 070-R	0.660	0.966
MAT 080	1.474	1.609
MAT 080-R	0.979	1.010

While the results for MAT 060-R and the MAT 070 states may be partially explained due to the higher overall pass rates, there are clearly some benefits attributable to partial credit in all of these comparisons. From the table, a large percentage, from around 15% to as high as 40% of the students in these comparisons, passed at least one module, but not enough modules to earn credit under the old developmental sequence, which would have, theoretically, meant that they were likely to fail the old developmental course. While this analysis cannot account for the possibility of a partial credit student working harder to attempt to pass the old developmental course, the analysis seems to indicate that partial credit appears to, overall, help students progress rather than restrict them.

CHAPTER 5: CONCLUSIONS

Conclusions

Based on the findings listed above, the following conclusions were drawn for students in developmental and/or curriculum mathematics courses or modules at MCCC.

Conclusions based on the Preliminary Analysis.

Conclusion 1: Students who attempt a course or module for the second time generally have a lower pass or progression rate than those students who attempt that course or module for the first time. Students that attempt a course for the third or subsequent time generally have a similar pass or progression rate to those attempting the course for the second time.

This study found that students attempting a course for the second or subsequent time had lower pass rates than those attempting the course for the first time. Repeating a developmental mathematics course was also found to have a negative effect on future course pass rates in the study by Zientek, Ozel, Fong and Griffen (2013) mentioned in Chapter 2. In that study, repeating a course was the fourth most predictive variable for a course's final grade, trailing only course attendance and two measures of self-efficacy. Intuitively, it would appear that failing or withdrawing from a course would be seen by a student as an indicator of educational failure (Strowbridge, 1987), diminished self-efficacy, and a reiteration of a "fixed" mindset as described by Dweck (2006), thus leading to a lowering of future course pass rates. This would be especially true of developmental mathematics students (or developmental education students in general), since, as discussed previously, these students often did not do well in K-12 education (Center for Community College Student Engagement, 2016), or tend to be older and therefore may have been out of education for many years (Burley, Butner, & Cejda, 2001).

While the first part of this conclusion would seem to be readily apparent, the second part may not be as apparent. It would appear that the main drop in pass or progression rates occurs between the first attempt and the second attempt and, after that second attempt, the rates hold steady. Diminishing sample sizes may be a concern for this result (as there are few students who attempt the same course a third, fourth, or even fifth, time), but, in general, it appears that the first failure or repetition has the most effect on future pass or progression rates.

Also, this conclusion required adjusting the Markov model, adding repeat states (states marked with “-R”) to the model so as to preserve the Markov property and to account for the difference in pass or progression rates. It is possible that other studies of student progression in developmental education may not make any adjustments for student repeats, possibly leading to incorrect conclusions. It is, therefore, recommended that any future studies of student progression through developmental mathematics, or any other system where students progression somewhat linearly through a series of courses, check the progression of students who are repeating the course, so as to avoid conflating those students, who might have a lower progression rate, with students taking the course for the first time.

Conclusion 2: Students with a second attempt (or repeat) in a previous course or module have lower pass or progression rates in subsequent courses or modules than those students who do not have any previous repeats.

This result, as mentioned previously, was determined based on a concern about how to transition successful students from the repeat states. Comparing the pass and progression rates for students with a previous repeat, it was determined that the pass or progression rates for those students was significantly lower than those students who have no previous repeat. In essence, a previous repeat stays with the student, as least for subsequent mathematics courses.

It may appear that this result is contrary to common sense, since completion of a course or module should, according to one of the goals of developmental education, mean that the repeating student is academically prepared for the next course or module in sequence. However, it is important to note that students can have difficulties in a course for reasons other than academic preparedness (such as difficulties in work/life balance, family/child care issues, transportation issues, etc.), which could, consequently, lead to failure and a repeat. Most of these other issues do not necessarily resolve themselves once a student completes the course they had to repeat, and could, therefore, negatively affect the pass or progression rate of subsequent courses. Also, as described above, a previous repeat may be interpreted by the student in terms of diminished self-efficacy and as evidence of the “fixed” mindset (Strowbridge, 1987; Dweck, 2006).

It is important to note, particularly regarding this finding, that, due to the changes in the administrative withdrawal policy during the timeframe of the study, students failing a course (grades “F” or “R”) and student withdrawing from a course (grades “W”, "WP", and "WF") are being treated as the same. It is possible that this conclusion may relate primarily to failures as opposed to withdraws (i.e. a student who fails is more likely to fail, but withdraws do not affect future pass rates), or vice versa.

Also, while it is clear from the data that students with a previous repeat do not have the same pass or progression rates as those without a previous repeat, it has not been established that their pass rates are comparable to students who are repeating that course without a previous repeat. In short, the conclusion states that students in MAT 070 (for example) with a previous repeat do not have similar pass rates as students in MAT 070 without a previous repeat, but does not say that the previous repeat students have similar pass rates as students in the MAT 070-R state (the state to which these students were moved). This study placed these previous repeat students in the MAT 070-R state due to model parsimony and concerns about testing these groups that often have very small sample sizes, not due to any conclusion about the similarity of pass rates.

Conclusion 3: Students who place into a course or module by passing previous courses or modules (after controlling for repeats) have similar pass rates as those students who place into the course or module by other means.

This finding, one of the key tests of the Markov property that underlies this model, shows that, in general, passing a previous course or module puts students on a relatively even footing with those students who placed into a course or module directly. This is, again, in line with one of the goals of developmental education, which is to adequately prepare students for curriculum courses, or the next course in sequence.

Out of all 68 states tested (courses and modules with number chosen, both repeat and non-repeat states), there was only one state (MAT 161-R) that met the criteria for a significant difference in pass rate due to being placed by passing developmental coursework. However, it is worth noting that this is a repeat state (so these students have already attempted this course previously, and either failed or withdrew), with a fairly small overall sample size (n = 123) compared to the rest of the courses and modules in the study. A few other tests for courses and modules covering beginning algebra (MAT 070, Module 4, Chose 2, and Module 4, Chose 3) were close to satisfying the study's requirements, which may suggest an area of concern. However, on the whole, it appears that placement by passing previous courses is an appropriate placement for students (in that it is comparable to other placements in student pass rates), and is evidence that the Markov model is appropriate for this design.

Conclusions based on the Research Questions.

Next, we move to conclusions based on the research questions in the study. Most of these questions are concerned with differences in pass rates between the two developmental mathematics systems, the older course-based system (MAT 050-080 courses) and the new, emporium method modular system (Modules 1-8). These will be analyzed by comparing the cohorts of students in both systems (old and new). While the study had a small, mixed cohort (that took developmental courses under both systems), the results from that cohort were varied, so most of the conclusions below will focus on comparing the old system cohort to the new system cohort.

Also, many of the conclusions given below relate to findings for the pass rates of students in the new developmental mathematics sequence taking the highest pre-requisite curriculum mathematics course, MAT 171: Precalculus Algebra. Recall that, in the preliminary analysis of the study, the pass rates for MAT 161: College Algebra (the comparable course offered under the old developmental mathematics system) and MAT 171: Precalculus Algebra were found to be comparable, so those courses were combined and labelled as MAT 161, since there were more MAT 161 records. In the findings that follow, note that findings that refer to MAT 161 would, therefore, apply to students taking MAT 171 under the new developmental mathematics system.

Research Question 1.

Conclusion 4: Initial analysis shows that the old developmental mathematics system had a slightly higher curriculum mathematics completion rate (controlling for initial placement) than the new developmental mathematics system across all initial placements, but none were significantly higher. However, other factors may be affecting these results, which will be detailed below.

Overall first curriculum course completion rates for both developmental systems varies by initial placement starting at between 0-5% for the lowest placed developmental students, up to 43-53% for those placed into the highest developmental course. This agrees with previous studies that concluded that students initially placed lower would have lower curriculum course completion rates (Bahr 2008; Bailey, Jeong & Cho, 2010b; Hagedorn and Lester 2006). Students that were three levels below curriculum (which would be MAT 060/Module 1-3 for this study) had a curriculum course completion rate of between 10-13%, which is slightly higher, but comparable to, the 8% found in a nationwide study (Bailey, Jaggars, & Jenkins, 2015). For students placed directly into curriculum courses, the completion rates were much higher, around 79-85%. As noted above, the old developmental system generally had the higher percentages, but there are other factors that may be affecting these results.

Conclusion 4a: Students in the new developmental mathematics system tend to place lower than those in the old developmental mathematics system.

There is a larger percentage of students in the new developmental mathematics system placing into MAT 060/Modules 1-3 than in the old developmental mathematics system. While this study did not investigate the reasons for this difference, it should be noted that there were differences in the distribution of placement tests used in this study (the old system cohort tended to have Asset and Accuplacer/CPT test scores, while the new system cohort had more Compass, Plan, and NCDAP placement tests), so different placement tests cannot be ruled out as a reason for the difference in placement. Placement test results may also be confounded by student demographics (the Plan placement test, for instance, is only given to high school students who are attempting to earn college credit while in high school, so students placed by the Plan placement test would be disproportionately younger than the overall MCCC population). Also, particularly for the students taking the NCDAP test, calculators are not allowed at MCCC for the first two modules (and are not allowed in the classes on module tests and quizzes for Module 1 and half of Module 2), possibly leading many students who rely upon the calculator to fail that part of the NCDAP and be placed into Module 1 or 2.

Conclusion 4b: New developmental mathematics students also tend to stay in the developmental sequence longer, choosing to take MAT 080/Modules 6-8 in an attempt to qualify for MAT 161, as opposed to leaving the developmental sequence after MAT 070/Modules 4-5 for a lower pre-requisite curriculum mathematics course (such as MAT 140 or MAT 151).

Regarding this finding, it is important to note that, in recent years, MCCC has seen a shift in its student population, where the institution has gone from being a majority vocational program community college to have a majority of students who want to transfer to a four-year college or university. Recent changes in transfer articulation agreements between the University of North Carolina and North Carolina Community College System (North Carolina Community College System, 2014) have made it more likely that students will take MAT 171 (coded in this study as MAT 161, as mentioned above), rather than opting for a course like MAT 140, which is unlikely to transfer except as elective credit. This approach would seem to exacerbate any possible issues with developmental mathematics misalignment. It appears that the current system may force prospective college transfer students to go through the developmental courses and modules required to take the traditional, college algebra course MAT 171, when their anticipated program of study may not require that material, and would be better served taking a lower prerequisite course such as MAT 140 or MAT 151. Studies (Achieving the Dream, et al., 2015; Jaggars & Hodara, 2011; Pritchard, 1995; Tinto, 2012) have shown that such lower prerequisite courses tailored toward a student's program of study may be more suitable and lead to higher progression rates. While private colleges are not required to follow those same guidelines, many of them do, meaning students who wish to transfer to those institutions also are more likely to take MAT 171, and therefore would have the same concerns. As mentioned above, this course requires the full developmental mathematics sequence all the way through MAT 080/Modules 6-8, meaning that those students have to take more developmental courses or modules, and are, therefore, more likely not to progress to the curriculum course.

Conclusion 4c: Students who place into courses using the new Multiple Measures placement method (all of which are in the new developmental mathematics system) generally have lower pass rates than those who place by other methods, and significantly lower pass rates for MAT 161/171 in particular (as described in Conclusion 7).

A more detailed discussion of the Multiple Measures results will be given under Conclusion 7 (the conclusion for Research Question 4, the research question on Multiple Measures). However, it is worth noting that the same factors listed under Conclusion 4b regarding more students taking MAT 171 would also apply here as well.

Conclusion 4d: Students who have a previous repeat are significantly less likely to pass a curriculum mathematics course (controlling for starting placement) than those without a previous repeat.

This result is somewhat expected given the previous results on students with a previous repeat, since, logically, if those students have lower pass or progression rates on an individual course or module basis, that would lead to them having a lower overall rate of completing their first curriculum mathematics course. As will be seen in the results for Research Question 5 (Conclusion 8 below), students in the new developmental mathematics system have a lower chance of repeats due to partial credit, and, for those students in a nearly comparable situation to the old developmental mathematics courses, a higher number of mean modules passed.

The overall conclusion from the first research question is that it appears that the two developmental mathematics systems are fairly comparable, and that, while on a surface impression the old system appears slightly better in terms of first curriculum mathematics course completion (controlling for initial placement), changes in the student population regarding academic preparedness, placement, and goals may be important factors present in these results, all of which may be leading to lower curriculum completion rates for the new developmental mathematics sequence.

Research Question 2.

Conclusion 5: Regarding gender and ethnicity differences, females tend to initially be placed lower in both the old and the new developmental mathematics systems, but the rate of passing their first curriculum mathematics course is similar for both males and females (given similar initial starting placements) for both systems. Black/African-American students also tend to initially be placed lower in both systems as compared to Whites, and also tend to have lower rates of passing their first curriculum mathematics course than Whites (given similar starting placements), again for both systems. Hispanic and Other students were generally comparable to Whites in both placement and curriculum course completion, but with small sample sizes.

Most of the findings on females and Black/African-American students have lower initial placements agree with previous studies (Bettinger & Long, 2005; Grimes & David, 1999; Hagedorn, Siadat, Fogel, Nora & Pascarella, 1999; Penny, White & William, 1998). However, in this study, controlling for initial placement, females and males had comparable rates of completing their first curriculum mathematics course, while Black/African-American students had lower rates overall (although slightly under the criteria set for significance in this study) than Whites. The results for Hispanic and Other students (as being comparable to Whites) are encouraging, but should be viewed cautiously given the small sample sizes in some of the groups.

Research Question 3.

Conclusion 6: Pass rates for the old developmental course tend to be a steady percentage across all four courses, around a 50% pass rate for students taking the course for the first time and 30% for students who are repeating the course or have a previous repeat. Under the new developmental modules, the mean number of modules passed (controlled for how many modules the student chose to complete, which is linked to classroom time) varied. Students who are repeating or have a previous repeat had a lower mean than students who did not. Controlling for that, students choosing to complete just one module had similar mean number of modules completed. For students choosing to complete more than one module, students starting at Modules 1 and 7 had a larger mean number of modules completed, while students starting at Modules 2 and 6 having a smaller mean number of modules completed.

As we have seen throughout this study, repeating students and those with a previous repeat have lower pass and progression rates than students without any repeats, and this conclusion agrees with previous conclusions on this finding.

The old developmental courses had a fairly uniform course pass rate of around 50%, which is fairly comparable to other studies (Roska, Jenkins, Jaggers, Zeidenberg & Cho, 2009; Roueche & Roueche, 1993). The results for the new developmental system, however, are more complex. For students choosing to complete only one module, the mean number of modules completed are not significantly different. However, for students who choose to complete two or three modules, the results show some significant differences in mean number of modules passed based on starting module, with students starting at Modules 1 and 7 having a statistically higher mean and those starting at

Modules 2 and 6 having a statistically lower mean. To put this result in context, it should be noted that the new developmental modules are not of uniform length:

Module 1: 8 sections

Module 2: 15 sections

Module 3: 13 sections

Module 4: 10 sections

Module 5: 9 sections

Module 6: 18 sections

Module 7: 8 sections

Module 8: 8 sections

Other than Module 8 (which was not included in the tests for students choosing more than one module since it is the last module in the new developmental mathematics sequence), the smaller, 8-section Modules 1 and 7 had higher means, and the largest two modules, Module 2 (with 15 sections) and Module 6 (with 18 sections) had the lowest means. A more detailed analysis of these results is beyond the scope of this study; however, it would appear that starting module length is an important factor in the mean number of modules completed by a student (controlling for how many modules that student chose to complete).

Research Question 4.

Conclusion 7: Students placed by Multiple Measures have slightly lower, but comparable pass rates to students placed by other methods for all curriculum courses, except for MAT 161/171, where the Multiple Measures pass rate is significantly lower.

Alternate methods of placement, such as Multiple Measures, are becoming more common as colleges and college systems try to determine more efficient ways to place students into courses, and some studies (Belfield & Crosta, 2012; Ngo & Kwon, 2015; Scott-Clayton, 2012), have shown that students placed using these methods are as effective in their college-level courses as those placed by other methods. From this study, it would appear that Multiple Measures placement is fairly comparable (pass rates for Multiple Measures students are slightly lower, but not significantly lower) for all of the curriculum courses in the study, except for MAT 171, where there is a very large difference (nearly 18 percentage points). It is also worth noting that, under the new developmental mathematics system (which is the system in place when Multiple Measures was implemented), MAT 171 is the only course in the study, and the only gateway mathematics course, with a pre-requisite of all eight developmental modules. All other curriculum mathematics courses in this study have pre-requisites going through, at most, Module 5. So, it would appear that Multiple Measures may accurately place students into curriculum mathematics courses with a pre-requisite of Module 5 or less, but not for a pre-requisite of Module 8. This is a particularly important finding since, as mentioned in the discussion of Conclusion 4b, more students are taking MAT 171 due to changes in transfer agreements, so these results will affect more students than would have been the case previously.

There are discussions currently under way in the North Carolina Community College System regarding the success of students placed in Multiple Measures. One topic being considered whether a higher high school GPA threshold (such as a GPA of 3.0 as opposed to the current policy’s 2.6) may lead to more accurate placement. While this study did not address high school GPA for the students placed by Multiple Measures, the findings here would suggest that any gains in placement accuracy by changing the GPA to 3.0 would primarily be seen in the students taking MAT 171.

There are also some important limitations to this finding. Multiple Measures placement is a policy that only applied to students who graduated from a high school in North Carolina within the past five years. Therefore, the students in this study that were placed by Multiple Measures are possibly quite different from the total student population of MCCC regarding age (most of these students will be between the ages of 17 and 25) and in-state residence (most will be in-state students), two student demographic variables that were not included in this study. It is possible that the results for Multiple Measures could be confounded by student age and in-state status. Further, since high school GPA (a factor used to determine if a student qualifies for Multiple Measures) was not used for any placement purposes at MCCC prior to the implementation of Multiple Measures, that information was not recorded, therefore making it difficult to determine if any of the students in the old developmental system would have qualified for Multiple Measures had that policy been in effect when they were admitted to MCCC. This could result in a type of selection bias in these results, and conclusions based on these results should be viewed with this possible selection bias in mind.

Research Question 5.

Conclusion 8: A comparison of modules passed under the new developmental mathematics system with students comparably placed in the old developmental mathematics system shows that, although the total completion rate (passing all chosen modules) is lower for the new developmental mathematics system, the mean number of modules completed (converting the old courses to the module system) is higher for the new developmental mathematics system, primarily due to students receiving credit for the modules that they passed even though they did not pass the course (i.e. partial credit). This is particularly true of students who are repeating or have repeated a course or module.

As noted in this conclusion, the ability of students to receive partial credit leads to a higher mean number of modules completed, which could be seen as one of the key advantages of the new developmental mathematics system.

Of particular interest is the fact that students with repeats seem to have a larger gain in mean number of modules completed. There could be a number of reasons for this result. One possibility is that the awarding of partial credit helps to encourage a “growth” mindset as theorized by Dweck (2006), which would be particularly helpful for students who have already had to repeat a course, since repeating a course would reinforce a “fixed” mindset. Another possibility is that partial credit encourages students who are feeling overwhelmed by the bulk of material covered (a group more likely to be composed of students with repeats) to complete part of the course to receive some credit, whereas under the old system they may have withdrawn out of frustration (recall that withdraws are considered to be equivalent to failures in this study). A third possibility is that partial credit allows students who work at a slower pace (again, a group that is more likely to be composed of students with repeats) to receive credits for the modules they complete at their desired pace, as opposed to being forced to move at the pace required to complete all the material, which might make them more likely to fail or withdraw.

Issues and Limitations

While this study attempted to be as comprehensive as possible in evaluating the two developmental mathematics systems, there are several limitations to the results of this study, some of which were described in Chapter 1. First, the study is restricted to a single community college in North Carolina, and uses the developmental mathematics system designed for use in North Carolina, so extension of these results outside of North Carolina community colleges may be difficult. Also, since individual community colleges were allowed to choose the structure and method of instruction of the new developmental mathematics sequence at their college, other North Carolina community colleges using a different structure or method of instruction may have different results. In addition, while MCCC is often larger, but fairly comparable, to most of the other community colleges in the North Carolina Community College System, student demographic trends at MCCC might be different than those of comparable colleges, and, as has been shown in the results, demographic variables such as gender and ethnicity can affect the results of students in both developmental mathematics systems. Finally, community colleges in North Carolina have other options for gateway curriculum mathematics courses than just the courses used in this study (particularly for some Associate in Applied Science vocational programs), which could lead to different results than the results found in this study.

Preliminary Analysis.

In the preliminary analysis, some courses (MAT 151 and MAT 152, MAT 161 and MAT 171) were combined together due to similar material covered, similar pass rates, and to encourage model parsimony. Other gateway curriculum mathematics courses taught at other institutions may not be suited to this type of combination, so combination of other courses should be considered carefully before testing.

Also, as mentioned previously, due to changes in MCCC's administrative withdrawal policy, failures and withdraws are considered by this study as the same. However, there may be valid differences in students who fail a course versus those who withdraw from a course for which this study, due to those administrative withdrawal policy changes, cannot account. Further, colleges differ in their withdrawal policies, both in the time frame for students to withdraw, the ability and willingness of faculty members to withdraw students via administrative withdrawal, and the requirements for faculty members to withdraw students via administrative withdrawal. Changes in any of these could lead to differences in the results of this study.

Previous Repeats.

This study noted a difference in pass and progression rates of students who has a previous repeat as compared to those who were in the same course but did not have a previous repeat. However, as a retrospective study that did not have direct access to the students in the study, there is no way to determine the reason for a student's repeat, so there would be no way to determine if the reason for a student having to repeat the course was no longer valid (for example, a student may have had to withdraw from a course due to a work conflict, but retaking the course the next semester at a different time or day might no longer cause the student a work conflict). Also, as noted above, failures and withdraws are considered the same in this study, so any difference in the effect of previous repeats due to failure of a course versus withdrawing from a course were unable to be discerned through this study.

Placement Tests.

This study viewed all of the different placement tests used by MCCC over the timeframe of the study (Compass, Asset, CPT, Plan, and NCDAP) to be equally reliable and valid for the purposes of placement (a full analysis of the validity and reliability of these placement tests is beyond the scope of this study). North Carolina community colleges are given a choice as to which of these tests to administer at their college and, although placement scores can be transferred from one North Carolina community college to another, most students end up taking the placement test or tests given by the community college where they are enrolled. Thus, differences in the placement test given could lead to different results. Also, the newest test, the NCDAP, has only been used for a limited time (about two years as of the end of the timeframe of the study), and so may not be as thoroughly tested for validity and reliability as the other placement tests.

Multiple Measures, High School GPA, and Support Courses.

As mentioned in the discussion of Conclusion 7, Multiple Measures uses a high school GPA criterion of 2.6 for placement purposes; however, some other studies are investigating this 2.6 GPA criterion, suggesting that a GPA of 3.0 might be more accurate for placement purposes. This study did not address high school GPA in its evaluation of Multiple Measures, so it cannot address whether a GPA of 2.6 or 3.0 would be a better criterion for Multiple Measures placement. Also, the number of students under the old developmental system that could have qualified for Multiple Measures cannot be determined from the existing data (due to a lack of high school GPA scores), making it difficult to determine if selection bias is a factor in these results. Further, the Multiple Measures findings could be confounded by student demographic factors (such as age and in-state status) that are parts of the criteria for Multiple Measures placement, but not included in this study.

Recently the North Carolina Community College System has allowed colleges to offer a support course (MAT 001) for students taking MAT 140, MAT 151/152, and MAT 161/171 to assist them in passing these courses. This MAT 001 support course is recommended at some colleges, particularly for Multiple Measures students whose high school GPA is between 2.6 and 3.0. MCCC implemented this new MAT 001 support course for its MAT 152 and MAT 171 courses during the last year of the study's timeframe, but there was not a sufficient sample size of students taking these MAT 001 support course, given all of the different groups that this study was investigating, so any analysis of the support courses was dropped. Other colleges with more robust data sets and more students in these MAT 001 support courses may find that these courses have significant effects on the conclusions drawn from this study.

Suggestions for Further Research

Given the design and results of this study, and the issues and limitations discussed above, the following areas are suggested as further avenues for research.

First, similar studies at other community colleges in North Carolina should be performed so as to determine if the conclusions drawn from this study are localized just to MCCC, or are generalizable to other colleges in the North Carolina Community College System. The Markov chain model itself is generalizable to differences in instructional delivery and method that would be present at other colleges, although those differences will have to be represented in the model by the use of indicator variables. Any differences in these results due to institutional differences in developmental course structure or method of delivery would be important findings for the North Carolina Community College System, so expansion of this study's design to colleges that differ in structure or design would be particularly useful.

Second, to help ensure that proper controls for student placement and repeat status were implemented, this study used a large number of single variable (univariate) tests. In some instances, where variable interaction is less of a concern, more multivariate techniques may be indicated and help to reduce the family-wide error rate in a more suitable fashion than greatly restricting alpha values by using the Sidak correction. Even more sophisticated statistical techniques, such as generalized hierarchical linear modeling, cross classification models, or Markov Chain Monte Carlo methods could also be employed to answer these research questions more thoroughly, given a sufficiently large sample size. These techniques would also be useful to determine the effects of variables that this study assumed were equal across the two developmental systems, such as instructor or class effects.

Next, the conclusion regarding students having lower pass or progression rates based on a previous repeat should be more fully investigated. As mentioned previously, this study only concluded that students with previous repeats have lower pass and progression rates than students without a repeat, but did not conclude that they had the same pass or progression rates as students repeating the same course (since there was not a large enough sample size for all, or most, of the possible combinations). A larger study with a sufficient sample size might be able to answer this question, and be able to determine if the pass and progression rates are actually statistically similar. If not, the larger sample size might be able to support adding Previous Repeat states to the model, as opposed to simply classifying students with previous repeats in to the Repeat ("-R") states. This type of study could also possibly determine if there is a time limit or course progression limit to the difference in pass and progression rates (i.e. if this difference disappears after a year, or after completion two courses in sequence with repeats, for example).

A big limitation of this study is the combining of students who fail the course with students who withdraw from the course, due to the changes in administrative withdrawal. Another possible avenue of exploration is analyzing the difference, if any, in pass and progression rates for student who fail a course and repeat it versus students who withdraw from a course and repeat it. This could also extend to different withdraw grades (Withdraw Passing versus Withdraw Failing versus Failing) and to different reasons for withdrawing, provided that the reason for withdrawal was determined.

Further analysis of gender and ethnicity effects are also suggested, especially regarding Black/African-American students (who were lower in both placement and progression) and for Hispanic students (a growing population in North Carolina community colleges, but not having a sufficient sample size in this study for full analysis). In addition to these demographic variables, other student characteristics, such as age, first generation status, and Pell eligibility, could also be investigated for differences in progression and curriculum mathematics course completion.

Finally, the more recent changes that occurred near the end of the timeframe of the study, such as the implementation of the new NCDAP (with its individualized module testing, so that students could be placed out of modules in a non-linear fashion), the MAT 001 support courses, and suggestions of differences in students placed by Multiple

Measures with a higher GPA of 3.0 could be investigated for their effects on progression and curriculum mathematics course completion. A small percentage of students in this study did have non-linear placements due to the NCDAP (defined here as a student receiving credit for modules out of sequence, such as receiving credit for Modules 1, 2, and 4, but not for Module 3), but not enough to be able to accurately portray those results as a part of this study. Non-linear placement has the potential of greatly accelerating some students' progress through the new developmental mathematics sequence, and so is worthy of investigation. As mentioned previously, there was not enough students taking the new MAT 001 support courses to allow for proper investigation in this study, but these courses could have dramatic effects on curriculum mathematics course completion. Also, given the results of Multiple Measures placement for students in MAT 171, now a key course for college transfer, research into possible changes or modifications of Multiple Measures to address this issue, and controls for age and in-state status (if more complete data were available), as well as more thorough studies of the differences between Multiple Measures students, and comparable students under the old developmental system, are especially warranted.

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APPENDIX A: TABLES

Table 1:

Preliminary analysis: State reduction: MAT 151 & 152 and MAT 161 & 171

Course	*n*	Success %	*Z*	*p*	ES
MAT 151	1666	71.31%	1.80789	0.07062	0.03954
MAT 152	425	66.82%			

Course	*n*	Success %	*Z*	*p*	ES
MAT 161	2132	64.35%	-1.40188	0.16095	0.02140
MAT 171	2160	66.39%			

Note:

Effect size calculated using Z/sqrt(n) method

Table 2
Preliminary analysis: First vs. subsequent curriculum math courses

First/Subsequent Course	n	Success %	*Z*	*p*	ES
Course: MAT 110					
First	90	75.56%	-0.56779	0.57018	0.05952
Subsequent	1	100.00%			
Course: MAT 115					
First	685	76.06%	-2.06157	0.03925	0.07721
Subsequent	28	92.86%			
Course: MAT 121					
First	506	76.28%	-1.04313	0.29689	0.04476
Subsequent	37	83.78%			
Course: MAT 140					
First	3445	70.60%	-1.37847	0.16806	0.02299
Subsequent	149	75.84%			
Course: MAT 151					
First	1132	66.17%	-4.60442	4.14E-06	0.10069
Subsequent	959	75.39%			
Course: MAT 161					
First	3641	64.71%	-2.18171	0.02913	0.03330
Subsequent	651	69.12%			
Course: MAT 171					
First	244	61.89%	-1.11125	0.26646	0.04990
Subsequent	252	66.67%			

Notes:
MAT 120 had no students taking it as a subsequent curriculum math course
Effect size calculated using Z/sqrt(n) method

Table 3

Preliminary analysis: Attempts: Curriculum math courses

Attempt	n	Success %	*Z*	*p*	ES
Course: MAT 115					
First	614	76.71%	1.89608	0.05795	0.07426
Subsequent	38	63.16%			
Course: MAT 121					
First	437	76.66%	1.85812	0.06315	0.08526
Subsequent	38	63.16%			
Course: MAT 140					
First	2902	72.92%	8.01099	1.11E-15	0.13937
Subsequent	402	53.48%			
Course: MAT 151					
First	707	62.09%	0.62753	0.53031	0.02270
Subsequent	57	57.89%			
Course: MAT 161					
First	3014	66.95%	6.76314	1.35E-11	0.11638
Subsequent	363	49.04%			

Notes:

MAT 120 had no students taking it as a subsequent attempt

MAT 110 and MAT 175 has insufficient sample size for analysis purposes (# success or # failures < 5)

Effect size calculated using Z/sqrt(n) method

Table 4
Preliminary analysis: Attempts: Old developmental math courses

Attempt	n	Success %	*Z*	*p*	ES
Course: MAT 050					
First	626	51.76%	3.58370	0.00034	0.13402
Subsequent	89	31.46%			
Course: MAT 060					
First	4586	53.58%	13.51623	0.00000	0.18280
Subsequent	881	28.72%			
Course: MAT 070					
First	6572	53.94%	14.53938	0.00000	0.16002
Subsequent	1684	34.09%			
Course: MAT 080					
First	2316	46.80%	4.44785	0.00001	0.08290
Subsequent	563	36.41%			

Note:
Effect size calculated using Z/sqrt(n) method

Table 5
Preliminary analysis: Attempts: New developmental math courses

Attempt	n	*M*	*SD*	*t*	*df*	*p*	*d*
Start: Module 1							
First	2240	1.781	1.353	4.29683	2553	0.00001	0.08501
Subsequent	315	1.448	1.279				
Start: Module 2							
First	265	0.830	0.960	0.79129	307	0.21469	0.04502
Subsequent	44	0.705	0.978				
Start: Module 3							
First	265	0.938	1.012	2.14083	301	0.01655	0.12299
Subsequent	38	0.658	0.708				
Start: Module 4							
First	1814	1.307	1.118	8.70316	2403	2.94E-18	0.17747
Subsequent	591	0.888	0.978				
Start: Module 5							
First	324	0.806	0.815	1.88884	386	0.02983	0.09589
Subsequent	64	0.609	0.748				
Start: Module 6							
First	625	1.354	1.246	5.46183	798	3.15E-08	0.19310
Subsequent	175	0.817	1.120				
Start: Module 7							
First	150	1.167	0.878	-0.37234	178	0.35504	0.02775
Subsequent	30	1.233	0.898				
Start: Module 8							
First	75	0.693	0.464	0.74932	93	0.22778	0.07688
Subsequent	20	0.600	0.503				

Note:
Effect size calculated using Cohen's *d* = t/sqrt(n)

Table 6

Preliminary analysis: Higher attempts: Curriculum math courses

Attempt	n	Success %	*Z*	*p*	ES
Course: MAT 140					
Second	317	55.52%	1.58200	0.11365	0.07890
Third or higher	85	45.88%			
Course: MAT 161					
Second	305	49.84%	0.69940	0.48430	0.03671
Third or higher	58	44.83%			

Notes:

MAT 110, 115, 120, 121, 151, and 175 did not have enough students attempting the course for the third or higher time (n < 7 in all cases) to satisfy the test requirements

Effect size calculated using Z/sqrt(n) method

Table 7

Preliminary analysis: Higher attempts: Old developmental math courses

Attempt	n	Success %	*Z*	*p*	ES
Course: MAT 060					
Second	142	26.06%	-0.12070	0.90393	0.00943
Third or higher	22	27.27%			
Course: MAT 070					
Second	313	28.12%	-0.51400	0.60725	0.02548
Third or higher	94	30.85%			
Course: MAT 080					
Second	86	34.88%	0.37865	0.70495	0.03531
Third or higher	29	31.03%			

Notes:

MAT 050 did not have enough students attempting the course for the third or higher time (n=2) to satisfy the test requirements

Effect size calculated using Z/sqrt(n) method

Table 8
Preliminary analysis: Higher attempts: New developmental math courses

Attempt	n	*M*	*SD*	*t*	*df*	*p*	*d*
Start: Module 1							
Second	239	1.418	1.220	0.06526	313	0.47400	0.00368
Third or higher	76	1.408	1.145				
Start: Module 2							
Second	39	0.692	1.030	-0.41673	42	0.33950	0.06282
Third or higher	5	0.800	0.447				
Start: Module 4							
Second	396	0.914	0.980	1.12046	589	0.13149	0.04609
Third or higher	195	0.821	0.933				
Start: Module 5							
Second	44	0.750	0.811	2.43865	62	0.00881	0.30483
Third or higher	20	0.350	0.489				
Start: Module 6							
Second	120	0.800	1.112	-0.29766	173	0.38316	0.02250
Third or higher	55	0.855	1.145				

Note:
Modules 3, 7, and 8 had insufficient sample size for analysis purposes (n < 5 for one group)
Effect size calculated using Cohen's *d* = t/sqrt(n)

Table 9
Preliminary analysis: Previous repeats: Curriculum math courses

Previous Repeat	n	Success %	*Z*	*p*	ES
Course: MAT 115					
No Previous Repeat	575	77.74%	2.96833	0.00299	0.11625
Previous Repeat	77	62.34%			
Course: MAT 121					
No Previous Repeat	438	76.94%	2.37673	0.01747	0.10905
Previous Repeat	37	59.46%			
Course: MAT 140					
No Previous Repeat	2772	72.47%	5.53804	3.06E-08	0.09635
Previous Repeat	532	60.53%			
Course: MAT 151					
No Previous Repeat	670	63.73%	2.96320	0.00304	0.10720
Previous Repeat	94	47.87%			
Course: MAT 161					
No Previous Repeat	3067	65.76%	2.82280	0.00476	0.04858
Previous Repeat	310	57.74%			

Notes:

MAT 110, 120, and 175 did not have enough students with a previous repeat to satisfy the test requirements (# successes or # failures < 5)
Effect size calculated using Z/sqrt(n) method

Table 10
Preliminary analysis: Previous repeats: Old developmental math courses

Previous Repeat	n	Success %	*Z*	*p*	ES
Course: MAT 060					
No Previous Repeat	5259	50.41%	6.23640	4.48E-10	0.08435
Previous Repeat	208	28.37%			
Course: MAT 070					
No Previous Repeat	7631	51.83%	12.30026	0.00000	0.13537
Previous Repeat	625	26.24%			
Course: MAT 080					
No Previous Repeat	2509	47.75%	8.36111	0.00000	0.15583
Previous Repeat	370	24.59%			

Note:
Effect size calculated using Z/sqrt(n) method

Table 11
Preliminary analysis: Previous repeats: New developmental math courses

Previous Repeat	n	*M*	*SD*	*t*	*df*	*p*	*d*
Start: Module 1							
No Previous Repeat	2459	1.745	1.348	0.91651	2553	0.17974	0.01813
Previous Repeat	96	1.615	1.364				
Start: Module 2							
No Previous Repeat	277	0.780	0.970	-1.93625	307	0.02688	0.11015
Previous Repeat	32	1.094	0.856				
Start: Module 3							
No Previous Repeat	257	0.907	1.000	0.27116	292	0.39323	0.01581
Previous Repeat	37	0.865	0.855				
Start: Module 4							
No Previous Repeat	2072	1.261	1.116	7.38810	2403	1.02E-13	0.15065
Previous Repeat	333	0.847	0.920				
Start: Module 5							
No Previous Repeat	275	0.880	0.857	4.79576	386	1.16E-06	0.24347
Previous Repeat	113	0.513	0.599				
Start: Module 6							
No Previous Repeat	647	1.311	1.267	3.92354	798	0.00005	0.13872
Previous Repeat	153	0.922	1.061				
Start: Module 7							
No Previous Repeat	134	1.246	0.871	1.78444	178	0.03803	0.13300
Previous Repeat	46	0.978	0.882				
Start: Module 8							
No Previous Repeat	67	0.687	0.467	0.40288	93	0.34398	0.04133
Previous Repeat	28	0.643	0.488				

Note:
Effect size calculated using Cohen's *d* = t/sqrt(n)

Table 12
Preliminary analysis: Placement: Curriculum math courses

Placement	n	Success %	Z	p	ES
State: MAT 110					
Course	38	81.58%	0.66826	0.50397	0.07987
Other	32	75.00%			
State: MAT 115					
Course	354	81.64%	2.26393	0.02358	0.10045
Other	154	72.73%			
State: MAT 115-R					
Course	91	65.93%	0.62271	0.53347	0.06227
Other	9	55.56%			
State: MAT 121					
Course	216	82.41%	2.53240	0.01133	0.13614
Other	130	70.77%			
State: MAT 121-R					
Course	46	67.39%	0.80197	0.42257	0.10622
Other	11	54.55%			
State: MAT 140					
Course	1492	76.54%	1.85298	0.06389	0.03863
Other	809	73.05%			
State: MAT 140-R					
Course	610	62.46%	2.59350	0.00950	0.09632
Other	115	49.57%			
State: MAT 151					
Course	214	65.89%	0.72196	0.47032	0.03181
Other	301	62.79%			
State: MAT 151-R					
Course	100	50.00%	-0.18802	0.85086	0.01695
Other	23	52.17%			
State: MAT 161					
Course	848	72.52%	2.46663	0.01364	0.05048
Other	1540	67.66%			
State: MAT 161-R					
Course	344	61.63%	3.82387	0.00013	0.16883
Other	169	43.79%			

Table 12 (continued)

Preliminary analysis: Placement: Curriculum math courses

Placement	n	Success %	*Z*	*p*	ES
State: MAT 175					
Course	39	61.54%	-1.18537	0.23587	0.09947
Other	103	71.84%			
State: MAT 175-R					
Course	7	28.57%	-0.06362	0.94927	0.01543
Other	10	30.00%			

Notes:

Misplaced, Regress, and No Data placement students removed

States MAT 110-R, MAT 120 and MAT 120-R has too small a sample size for analysis (# successes or # failures < 5)

Effect size calculated using Z/sqrt(n) method

Table 13
Preliminary analysis: Placement: Old developmental math courses

Placement	n	Success %	*Z*	*p*	ES
State: MAT 060					
Course	263	51.71%	-0.69192	0.48899	0.01109
Other	3628	53.91%			
State: MAT 060-R					
Course	109	33.03%	1.21557	0.22415	0.04401
Other	654	27.37%			
State: MAT 070					
Course	2078	49.42%	-6.35189	2.13E-10	0.08353
Other	3705	58.08%			
State: MAT 070-R					
Course	990	32.12%	-1.25093	0.21096	0.03068
Other	673	35.07%			
State: MAT 080					
Course	1407	48.54%	-2.66630	0.00767	0.06074
Other	520	55.38%			
State: MAT 080-R					
Course	633	31.75%	-1.35078	0.17676	0.05024
Other	90	38.89%			

Notes:
Misplaced, Regress, and No Data placement students removed
Effect size calculated using Z/sqrt(n) method

Table 14
Preliminary analysis: Placement: New developmental math courses

Placement	n	*M*	*SD*	*t*	*df*	*p*	*d*
State: Module 1, Chose 3							
Course	21	1.667	1.065	-0.84065	1710	0.20033	0.02032
Other	1691	1.864	1.372				
State: Module 1-R, Chose 3							
Course	16	1.438	1.153	0.02757	240	0.48901	0.00177
Other	226	1.429	1.305				
State: Module 2, Chose 1							
Course	7	0.286	0.488	-1.02505	10	0.16475	0.29591
Other	5	0.600	0.548				
State: Module 2, Chose 2							
Course	72	0.694	0.866	-1.61476	85	0.05503	0.17312
Other	15	1.200	1.146				
State: Module 2, Chose 3							
Course	98	0.765	0.883	-1.14950	131	0.12622	0.09967
Other	35	1.029	1.248				
State: Module 3, Chose 1							
Course	61	0.672	0.676	0.70455	70	0.24171	0.08303
Other	11	0.546	0.522				
State: Module 3, Chose 3							
Course	95	1.095	1.177	-0.91321	99	0.18168	0.09087
Other	6	1.667	1.506				
State: Module 4, Chose 1							
Course	23	0.609	0.656	0.36799	45	0.35730	0.05368
Other	24	0.542	0.588				
State: Module 4, Chose 2							
Course	199	0.930	0.891	-2.43365	383	0.00770	0.12403
Other	186	1.161	0.972				
State: Module 4, Chose 3							
Course	387	1.308	1.068	-2.62951	1191	0.00433	0.07613
Other	806	1.489	1.206				
State: Module 4-R, Chose 1							
Course	18	0.389	0.608	0.57846	27	0.28387	0.10742
Other	11	0.273	0.467				
State: Module 4-R, Chose 2							
Course	124	0.589	0.765	-0.46830	172	0.32008	0.03550
Other	50	0.660	0.961				
State: Module 4-R, Chose 3							
Course	234	1.000	0.963	-1.03397	426	0.15087	0.04998
Other	194	1.103	1.077				

Table 14 continued

Preliminary analysis: Placement: New developmental math courses

Placement	n	*M*	*SD*	*t*	*df*	*p*	*d*
State: Module 5, Chose 1							
Course	79	0.620	0.514	0.37910	103	0.35270	0.03700
Other	26	0.577	0.504				
State: Module 5, Chose 3							
Course	42	1.119	1.152	-1.11026	52	0.13600	0.15109
Other	12	1.583	1.311				
State: Module 6, Chose 1							
Course	62	0.661	0.745	0.11104	71	0.45595	0.01300
Other	11	0.636	0.674				
State: Module 6, Chose 2							
Course	30	0.700	1.022	0.18961	39	0.42530	0.02961
Other	11	0.636	0.924				
Stae: Module 6, Chose 3							
Course	233	1.605	1.279	-0.40807	387	0.34173	0.02069
Other	156	1.660	1.322				
Stae: Module 6-R, Chose 3							
Course	152	1.079	1.204	1.45581	177	0.07361	0.10881
Other	27	0.741	1.095				

Notes:

Misplaced, Regress, and No Data placement students removed

All missing states had insufficient sample size (n < 5 for one or both groups) for analysis

Effect size calculated using Cohen's *d* = t/sqrt(n)

Table 15
Demographics of finalized data set

Category	n	Percent
Gender		
Female	9442	59.80%
Male	6323	40.04%
Unknown	25	0.16%
Race/Ethnicity		
White	10258	64.97%
Black/African-American	3867	24.49%
Hispanic (any race)	804	5.09%
Other	733	4.64%
Unknown	128	0.81%

Note:

Gender and Race/Ethnicity categories listed as given in application, race/ethnic categories under 2% grouped together as Other

Table 16
Chi-square test for final status by placement

Cohort	Final Status: Did Not Pass	Graduated	Passed	Still Enrolled	Chi-square	*df*	*p*	*Φ*
Placement: MAT 050								
Old	354	13	17	3	124.89182	6	1.53E-24	0.50537
New	33	2	0	18				
Mixed	31	8	4	6				
Placement: MAT 060/Module 1-3								
Old	2719	175	405	26	762.80262	6	1.67E-161	0.36042
New	1378	92	153	462				
Mixed	315	36	79	32				
Placement: MAT 070/Module 4-5								
Old	2403	154	1227	52	356.36064	6	6.65E-74	0.26108
New	645	57	244	149				
Mixed	169	23	74	31				
Placement: MAT 080/Module 6-8								
Old	311	14	345	9	95.40847	6	2.27E-18	0.32632
New	90	8	67	34				
Mixed	9	2	6	1				
Placement: Curriculum (Pre-req 070)								
Old	155	7	865	0	105.38645	3	1.08E-22	0.25664
New	107	12	405	49				
Placement: Curriculum (Pre-req 080)								
Old	134	1	602	4	61.76028	3	2.47E-13	0.19168
New	168	4	683	85				

Notes:
No curriculum students exist in the mixed cohort
Curriculum (Pre-req 060) had no students in the old cohort

Table 17
Comparison of pass vs no pass (only) final statuses by placement

Cohort	n	Pass %	Comparison	*Z*	*p*	ES
Placement: MAT 050						
Old	371	4.58%	Old vs. New	1.25641	0.20897	0.06251
New	33	0.00%	Old vs. Mixed	-1.74825	0.08042	0.08676
Mixed	35	11.43%	New vs. Mixed	-2.00178	0.04531	0.24275
Placement: MAT 060/Module 1-3						
Old	3124	12.96%	Old vs. New	2.93163	0.00337	0.04297
New	1531	9.99%	Old vs. Mixed	-3.84822	0.00012	0.06488
Mixed	394	20.05%	New vs. Mixed	-5.46839	4.54E-08	0.12464
Placement: MAT 070/Module 4-5						
Old	3630	33.80%	Old vs. New	3.62437	0.00029	0.05392
New	889	27.45%	Old vs. Mixed	1.07009	0.28458	0.01719
Mixed	243	30.45%	New vs. Mixed	-0.92397	0.35550	0.02746
Placement: MAT 080/Module 6-8						
Old	656	52.59%	Old vs. New	2.23242	0.02559	0.07829
New	157	42.68%	Old vs. Mixed	0.96540	0.33435	0.03727
Mixed	15	40.00%	New vs. Mixed	0.20028	0.84126	0.01527
Placement: Curriculum (Pre-req 070)						
Old	1020	84.80%	Old vs. New	2.79619	0.00517	0.07144
New	512	79.10%				
Placement: Curriculum (Pre-req 080)						
Old	736	81.79%	Old vs. New	0.77684	0.43725	0.01950
New	851	80.26%				

Notes:
No curriculum students exist in the mixed cohort
Curriculum (Pre-req 060) had no students in the old cohort
Effect size calculated using Z/sqrt(n) method

Table 18
Initial placement by cohort

Cohort	Initial Placement				
	MAT 050	MAT 060	MAT 070	MAT 080	Above MAT 080
Old	387 (3.87%)	3325 (33.27%)	3836 (38.38%)	1706 (17.07%)	741 (7.41%)
New	53 (1.09%)	1998 (41.27%)	1080 (22.31%)	771 (15.93%)	940 (19.40%)
Mixed	49 (5.93%)	462 (55.86%)	297 (35.91%)	18 (2.18%)	0 (0.00%)

Notes:

MAT 060 = MAT 060/Module 1-3, MAT 070 = MAT 070/Modules 4-5, MAT 080 = MAT 080/Modules 6-8

Mixed cohort has no students placing above MAT 080/Module 8 by design

Students whose first course was a curriculum course with a pre-requisite of MAT 060/Modules 1-3 were placed in MAT 070

Students whose first course was a curriculum course with a pre-requisite of MAT 070/Modules 4-5 were placed in MAT 080

Table 19
Chi-square test of curriculum course passed by pre-requisite (passed students only)

Cohort	Pre-requisite of Curriculum Course			Chi-square	*df*	*p*	*Φ*
	MAT 060	MAT 070	MAT 080				
Old	6 (0.15%)	2663 (65.46%)	1399 (34.39%)	268.38728	4	7.10E-57	0.21484
New	53 (3.03%)	828 (47.40%)	866 (49.57%)				
Mixed	8 (4.21%)	143 (75.26%)	39 (20.53%)				

Note:

MAT 060 = MAT 060/Module 1-3, MAT 070 = MAT 070/Modules 4-5, MAT 080 = MAT 080/Modules 6-8

Table 20
Final status by start state and cohort: Pass and did not pass only

	Cohort		
Final Status	Old	New	Mixed
Start State: MAT 050			
MAT 050	202 (54.45%)	32 (96.97%)	0 (0.00%)
MAT 060/Modules 1-3	98 (26.42%)	0 (0.00%)	16 (45.71%)
MAT 070/Modules 4-5	43 (11.59%)	1 (3.03%)	11 (31.43%)
Fail Curr Pre-req 060	0 (0.00%)	0 (0.00%)	0 (0.00%)
MAT 080/Modules 6-8	3 (0.81%)	0 (0.00%)	3 (8.57%)
Fail Curr Pre-req 070	8 (2.16%)	0 (0.00%)	1 (2.86%)
Comp Dev, No Course	0 (0.00%)	0 (0.00%)	0 (0.00%)
Fail Curr Pre-req 080	0 (0.00%)	0 (0.00%)	0 (0.00%)
Pass Curr Pre-req 060	0 (0.00%)	0 (0.00%)	0 (0.00%)
Pass Curr Pre-req 070	13 (3.50%)	0 (0.00%)	4 (11.43%)
Pass Curr Pre-req 080	4 (1.08%)	0 (0.00%)	0 (0.00%)
Start State: MAT 060/Modules 1-3			
MAT 050	11 (0.35%)	0 (0.00%)	0 (0.00%)
MAT 060/Modules 1-3	1756 (56.21%)	837 (54.67%)	92 (23.35%)
MAT 070/Modules 4-5	774 (24.78%)	360 (23.51%)	130 (32.99%)
Fail Curr Pre-req 060	0 (0.00%)	1 (0.07%)	1 (0.25%)
MAT 080/Modules 6-8	97 (3.10%)	128 (8.36%)	67 (17.01%)
Fail Curr Pre-req 070	69 (2.21%)	33 (2.16%)	13 (3.30%)
Comp Dev, No Course	0 (0.00%)	13 (0.85%)	10 (2.54%)
Fail Curr Pre-req 080	12 (0.38%)	6 (0.39%)	2 (0.51%)
Pass Curr Pre-req 060	2 (0.06%)	15 (0.98%)	4 (1.02%)
Pass Curr Pre-req 070	339 (10.85%)	108 (7.05%)	61 (15.48%)
Pass Curr Pre-req 080	64 (2.05%)	30 (1.96%)	14 (3.55%)
Start State: MAT 070/Modules 4-5			
MAT 050	0 (0.00%)	0 (0.00%)	0 (0.00%)
MAT 060/Modules 1-3	23 (0.63%)	2 (0.22%)	4 (1.65%)
MAT 070/Modules 4-5	1861 (51.27%)	343 (38.58%)	52 (21.40%)
Fail Curr Pre-req 060	1 (0.03%)	2 (0.22%)	0 (0.00%)
MAT 080/Modules 6-8	348 (9.59%)	245 (27.56%)	85 (34.98%)
Fail Curr Pre-req 070	119 (3.28%)	28 (3.15%)	8 (3.29%)
Comp Dev, No Course	0 (0.00%)	21 (2.36%)	14 (5.76%)
Fail Curr Pre-req 080	51 (1.40%)	4 (0.45%)	6 (2.47%)
Pass Curr Pre-req 060	3 (0.08%)	11 (1.24%)	0 (0.00%)
Pass Curr Pre-req 070	939 (25.87%)	174 (19.57%)	54 (22.22%)
Pass Curr Pre-req 080	285 (7.85%)	59 (6.64%)	20 (8.23%)

Table 20 continued

Final status by start state and cohort: Pass and did not pass only

	Cohort		
Final Status	Old	New	Mixed
Start State: MAT 080/Modules 6-8			
MAT 050	0 (0.00%)	0 (0.00%)	0 (0.00%)
MAT 060/Modules 1-3	2 (0.30%)	0 (0.00%)	0 (0.00%)
MAT 070/Modules 4-5	3 (0.46%)	0 (0.00%)	0 (0.00%)
Fail Curr Pre-req 060	0 (0.00%)	0 (0.00%)	0 (0.00%)
MAT 080/Modules 6-8	249 (37.96%)	67 (42.68%)	7 (46.67%)
Fail Curr Pre-req 070	23 (3.51%)	4 (2.55%)	1 (6.67%)
Comp Dev, No Course	0 (0.00%)	15 (9.55%)	0 (0.00%)
Fail Curr Pre-req 080	34 (5.18%)	4 (2.55%)	1 (6.67%
Pass Curr Pre-req 060	0 (0.00%)	1 (0.64%)	0 (0.00%)
Pass Curr Pre-req 070	126 (19.21%)	21 (13.38%)	3 (20.00%)
Pass Curr Pre-req 080	219 (33.38%)	45 (28.66%)	3 (20.00%)
Start State: Curriculum (Pre-req 060)			
MAT 050		0 (0.00%)	
MAT 060/Modules 1-3		0 (0.00%)	
MAT 070/Modules 4-5		0 (0.00%)	
Fail Curr Pre-req 060		3 (13.04%)	
MAT 080/Modules 6-8		0 (0.00%)	
Fail Curr Pre-req 070		0 (0.00%)	
Comp Dev, No Course		0 (0.00%)	
Fail Curr Pre-req 080		1 (4.35%)	
Pass Curr Pre-req 060		19 (82.61%)	
Pass Curr Pre-req 070		0 (0.00%)	
Pass Curr Pre-req 080		0 (0.00%)	
Start State: Curriculum (Pre-req 070)			
MAT 050	0 (0.00%)	0 (0.00%)	
MAT 060/Modules 1-3	0 (0.00%)	1 (0.20%)	
MAT 070/Modules 4-5	4 (0.39%)	0 (0.00%)	
Fail Curr Pre-req 060	0 (0.00%)	1 (0.20%)	
MAT 080/Modules 6-8	8 (0.78%)	0 (0.00%)	
Fail Curr Pre-req 070	141 (13.82%)	103 (20.12%)	
Comp Dev, No Course	0 (0.00%)	0 (0.00%)	
Fail Curr Pre-req 080	2 (0.20%)	2 (0.39%)	
Pass Curr Pre-req 060	0 (0.00%)	0 (0.00%)	
Pass Curr Pre-req 070	850 (83.33%)	402 (78.52%)	
Pass Curr Pre-req 080	15 (1.47%)	3 (0.59%)	

Table 20 continued

Final status by start state and cohort: Pass and did not pass only

	Cohort		
Final Status	Old	New	Mixed
Start State: Curriculum (Pre-req 080)			
MAT 050	0 (0.00%)	0 (0.00%)	
MAT 060/Mod 1-3	0 (0.00%)	0 (0.00%)	
MAT 070/Mod 4-5	0 (0.00%)	0 (0.00%)	
Fail Curr Pre-req 060	0 (0.00%)	0 (0.00%)	
MAT 080/Mod 6-8	2 (0.27%)	0 (0.00%)	
Fail Curr Pre-req 070	11 (1.49%)	6 (0.71%)	
Comp Dev, No Course	0 (0.00%)	0 (0.00%)	
Fail Curr Pre-req 080	121 (16.44%)	161 (18.84%)	
Pass Curr Pre-req 060	0 (0.00%)	1 (0.12%)	
Pass Curr Pre-req 070	24 (3.26%)	23 (2.71%)	
Pass Curr Pre-req 080	578 (78.53%)	659 (77.53%)	

Notes:

Old cohort had no students with a start state of Curriculum (pre-req 060)

Mixed cohort has no students starting in curriculum courses by design

Table 21

Percentage of students with a repeat, by cohort

Cohort	n	Repeat %	*Z*	*p*	ES
Old	9995	21.14%	-16.57523	0.00000	0.13550
New	4968	10.21%			

Note:

Effect size calculated using Z/sqrt(n) method

Table 22
Final state of students by cohort and repeat (pass and did not pass only)

Repeat	n	Pass %	*Z*	*p*	ES
Cohort: Old					
No Repeat	7522	38.54%	8.82934	0.00000	0.09041
Repeat	2015	27.89%			
Cohort: New					
No Repeat	3607	40.39%	4.21957	0.00002	0.06676
Repeat	388	29.38%			
Cohort: Mixed					
No Repeat	188	30.32%	2.50691	0.01218	0.09558
Repeat	500	21.20%			

Note:
Effect size calculated using Z/sqrt(n) method

Table 23
Initial Placement by Cohort and Gender (with percentage)

Gender	Initial Placement					Chi-square	*df*	*p*	*Φ*
	MAT 050	MAT 060	MAT 070	MAT 080	Above MAT 080				
Cohort: Old									
Female	258 (4.33%)	2181 (36.61%)	2146 (36.02%)	985 (16.53%)	388 (6.51%)	97.12752	4	4.02E-20	0.09867
Male	129 (3.21%)	1138 (28.32%)	1679 (41.79%)	720 (17.92%)	352 (8.76%)				
Cohort: New									
Female	32 (1.09%)	1378 (46.93%)	607 (20.67%)	412 (14.03%)	507 (17.27%)	75.96431	4	1.25E-15	0.12373
Male	21 (1.04%)	701 (34.60%)	512 (25.27%)	360 (17.77%)	432 (21.32%)				
Cohort Mixed:									
Female	32 (5.84%)	338 (61.68%)	169 (30.84%)	8 (1.46%)	0 (0.00%)	25.83471	4	0.00003	0.17675
Male	17 (6.09%)	124 (44.44%)	128 (45.88%)	10 (3.58%)	0 (0.00%)				

Note:

MAT 060 = MAT 060/Module 1-3, MAT 070 = MAT 070/Modules 4-5, MAT 080 = MAT 080/Modules 6-8

Mixed cohort has no students placing above MAT 080/Module 8 by design

Students whose first course was a curriculum course with a pre-requisite of MAT 060/Modules 1-3 were placed in MAT 070

Students whose first course was a curriculum course with a pre-requisite of MAT 070/Modules 4-5 were placed in MAT 080

Table 24
Chi-square test for final status by placement, cohort and gender

	Final Status							
Gender	Did Not Pass	Graduated	Passed	Still Enrolled	Chi-square	*df*	*p*	*Φ*
Cohort & Placement: Old Cohort, MAT 050								
Female	231	12	13	2	4.89924	3	0.17933	0.11251
Male	123	1	4	1				
Cohort & Placement: New Cohort, MAT 050								
Female	17	2	0	13	NA	3	NA	NA
Male	16	0	0	5				
Cohort & Placement: Mixed Cohort, MAT 050								
Female	20	6	2	4	0.75885	3	0.85928	0.12445
Male	11	2	2	2				
Cohort & Placement: Old Cohort, MAT 060/Modules 1-3								
Female	1748	142	271	20	22.18146	3	0.00006	0.08175
Male	965	33	134	6				
Cohort & Placement: New Cohort, MAT 060/Modules 1-3								
Female	878	74	108	318	13.26433	3	0.00410	0.07836
Male	495	18	63	206				
Cohort & Placement: Mixed Cohort, MAT 060/Modules 1-3								
Female	223	29	58	27	3.78209	3	0.28598	0.09058
Male	91	7	21	5				
Cohort & Placement: Old Cohort, MAT 070/Modules 4-5								
Female	1364	122	628	32	46.93222	3	3.59E-10	0.11077
Male	1028	32	599	20				
Cohort & Placement: New Cohort, MAT 070/Modules 4-5								
Female	328	44	134	95	20.42914	3	0.00014	0.13659
Male	317	13	110	54				
Cohort & Placement: Mixed Cohort, MAT 070/Modules 4-5								
Female	101	13	41	14	2.37562	3	0.49819	0.08944
Male	68	10	33	17				

Table 24 continued
Chi-square test for final status by placement, cohort and gender

	Final Status							
Gender	Did Not Pass	Graduated	Passed	Still Enrolled	Chi-square	*df*	*p*	*Φ*
Cohort & Placement: Old Cohort, MAT 080/Modules 6-8								
Female	186	10	195	7	3.11537	3	0.37418	0.06774
Male	125	4	150	2				
Cohort & Placement: New Cohort, MAT 080/Modules 6-8								
Female	42	5	40	11	7.61419	3	0.05470	0.19561
Male	48	3	27	23				
Cohort & Placement: Mixed Cohort, MAT 080/Modules 6-8								
Female	5	0	2	1	3.60000	3	0.30802	0.44721
Male	4	2	4	0				
Cohort & Placement: Old Cohort, Above MAT 080/Module 8								
Female	66	1	319	2	1.56006	3	0.66848	0.04592
Male	68	0	282	2				
Cohort & Placement: New Cohort, Above MAT 080/Module 8								
Female	89	3	379	36	5.99635	3	0.11179	0.07991
Male	78	1	304	49				

Notes:
No Above MAT 080/Module 8 students exist in the mixed cohort

Table 25

Comparison of pass vs no pass (only) final statuses by placement, cohort, and gender

Gender	n	Pass %	*Z*	*p*	ES
Cohort & Placement: Old Cohort, MAT 050					
Female	244	5.33%	0.95207	0.34106	0.04943
Male	127	3.15%			
Cohort & Placement: New Cohort, MAT 050					
Female	17	0.00%	NA	NA	NA
Male	16	0.00%			
Cohort & Placement: Mixed Cohort, MAT 050					
Female	22	9.09%	-0.56547	0.57175	0.09558
Male	13	15.38%			
Cohort & Placement: Old Cohort, MAT 060/Modules 1-3					
Female	2019	13.42%	0.97569	0.32922	0.01747
Male	1099	12.19%			
Cohort & Placement: New Cohort, MAT 060/Modules 1-3					
Female	986	10.95%	-0.20270	0.83937	0.00516
Male	558	11.29%			
Cohort & Placement: Mixed Cohort, MAT 060/Modules 1-3					
Female	281	20.64%	0.42216	0.67291	0.02129
Male	112	18.75%			
Cohort & Placement: Old Cohort, MAT 070/Modules 4-5					
Female	1992	31.53%	-3.34423	0.00083	0.05559
Male	1627	36.82%			
Cohort & Placement: New Cohort, MAT 070/Modules 4-5					
Female	462	29.00%	1.08264	0.27897	0.03631
Male	427	25.76%			
Cohort & Placement: Mixed Cohort, MAT 070/Modules 4-5					
Female	142	28.87%	-0.63436	0.52585	0.04069
Male	101	32.67%			

Table 25 continued

Comparison of pass vs no pass (only) final statuses by placement, cohort, and gender

Gender	n	Pass %	*Z*	*p*	ES
Cohort & Placement: Old Cohort, MAT 080/Modules 6-8					
Female	381	51.18%	-0.85152	0.39448	0.03325
Male	275	54.55%			
Cohort & Placement: New Cohort, MAT 080/Modules 6-8					
Female	82	48.78%	1.61725	0.10583	0.12907
Male	75	36.00%			
Cohort & Placement: Mixed Cohort, MAT 080/Modules 6-8					
Female	7	28.57%	-0.84515	0.39802	0.21822
Male	8	50.00%			
Cohort & Placement: Old Cohort, Above MAT 080/Module 8					
Female	385	82.86%	0.80157	0.42280	0.02957
Male	350	80.57%			
Cohort & Placement: New Cohort, Above MAT 080/Module 8					
Female	468	80.98%	0.51164	0.60890	0.01755
Male	382	79.58%			

Notes:

No Above MAT 080/Module 8 students exist in the mixed cohort

Effect size calculated using Z/sqrt(n) method

Table 26

Initial Placement by Cohort and Race/Ethnicity (with percentages)

	Initial Placement								
Race	MAT 050	MAT 060	MAT 070	MAT 080	Above MAT 080	Chi-square	*df*	*p*	*Φ*
Cohort: Old									
White	148 (2.18%)	1845 (27.22%)	2885 (42.56%)	1290 (19.03%)	611 (9.01%)	786.42586	12	1.35E-160	0.28077
Black/AA	214 (9.00%)	1200 (50.48%)	627 (26.38%)	273 (11.49%)	63 (2.65%)				
Hispanic	3 (0.82%)	123 (33.61%)	153 (41.80%)	62 (16.94%)	25 (6.83%)				
Other	22 (4.85%)	151 (33.26%)	160 (35.24%)	80 (17.62%)	41 (9.03%)				
Cohort: New									
White	12 (0.40%)	1042 (34.59%)	760 (25.23%)	549 (18.23%)	649 (21.55%)	382.28853	12	2.12E-74	0.27757
Black/AA	32 (2.64%)	761 (62.69%)	211 (17.38%)	103 (8.48%)	107 (8.81%)				
Hispanic	3 (0.76%)	138 (35.11%)	87 (22.14%)	62 (15.78%)	103 (26.21%)				
Other	6 (1.75%)	138 (40.23%)	61 (17.78%)	58 (16.91%)	80 (23.32%)				
Cohort: Mixed									
White	19 (4.07%)	236 (50.54%)	201 (43.04%)	10 (2.14%)	0 (0.00%)	58.06106	12	5.08E-08	0.26497
Black/AA	29 (10.51%)	181 (65.58%)	64 (23.19%)	2 (0.73%)	0 (0.00%)				
Hispanic	0 (0.00%)	21 (46.67%)	21 (46.67%)	3 (6.67%)	0 (0.00%)				
Other	1 (2.56%)	24 (61.54%)	11 (28.21%)	3 (7.69%)	0 (0.00%)				

Note:

MAT 060 = MAT 060/Module 1-3, MAT 070 = MAT 070/Modules 4-5, MAT 080 = MAT 080/Modules 6-8

Mixed cohort has no students placing above MAT 080/Module 8 by design

Students whose first course was a curriculum course with a pre-requisite of MAT 060/Modules 1-3 were placed in MAT 070

Students whose first course was a curriculum course with a pre-requisite of MAT 070/Modules 4-5 were placed in MAT 080

Table 27
Chi-square test for final status by placement, cohort and race/ethnicity

	Final Status							
Race	Did Not Pass	Graduated	Passed	Still Enrolled	Chi-square	*df*	*p*	*Φ*
Cohort & Placement: Old Cohort, MAT 050								
White	132	6	10	0	13.76898	9	0.13078	0.18862
Black/AA	198	7	6	3				
Hispanic	2	0	1	0				
Other	22	0	0	0				
Cohort & Placement: New Cohort, MAT 050								
White	7	1	0	4	NA	9	NA	NA
Black/AA	21	1	0	10				
Hispanic	2	0	0	1				
Other	3	0	0	3				
Cohort & Placement: Mixed Cohort, MAT 050								
White	12	4	2	1	NA	9	NA	NA
Black/AA	19	4	2	4				
Hispanic	0	0	0	0				
Other	0	0	0	1				
Cohort & Placement: Old Cohort, MAT 060/Modules 1-3								
White	1481	105	250	9	38.04572	9	0.00002	0.10707
Black/AA	1020	63	106	11				
Hispanic	95	4	21	3				
Other	117	3	28	3				
Cohort & Placement: New Cohort, MAT 060/Modules 1-3								
White	659	51	93	239	35.56087	9	0.00005	0.13079
Black/AA	550	30	41	140				
Hispanic	72	7	10	49				
Other	92	4	9	33				
Cohort & Placement: Mixed Cohort, MAT 060/Modules 1-3								
White	154	12	49	21	22.59857	9	0.00716	0.22117
Black/AA	133	22	18	8				
Hispanic	12	1	7	1				
Other	16	1	5	2				

Table 27 continued
Chi-square test for final status by placement, cohort and race/ethnicity

	Final Status							
Race	Did Not Pass	Graduated	Passed	Still Enrolled	Chi-square	*df*	*p*	*Φ*
Cohort & Placement: Old Cohort, MAT 070/Modules 4-5								
White	1738	122	984	40	36.52310	9	0.00003	0.09773
Black/AA	451	21	147	8				
Hispanic	93	5	51	4				
Other	109	6	45	0				
Cohort & Placement: New Cohort, MAT 070/Modules 4-5								
White	430	36	180	97	32.25169	9	0.00018	0.17162
Black/AA	142	13	29	22				
Hispanic	34	8	24	19				
Other	39	0	11	11				
Cohort & Placement: Mixed Cohort, MAT 070/Modules 4-5								
White	111	17	53	21	6.26735	9	0.71289	0.14502
Black/AA	40	2	15	7				
Hispanic	12	3	5	1				
Other	7	1	1	2				
Cohort & Placement: Old Cohort, MAT 080/Modules 6-8								
White	222	11	270	7	18.99017	9	0.02528	0.16724
Black/AA	63	0	42	2				
Hispanic	11	0	15	0				
Other	15	3	18	0				
Cohort & Placement: New Cohort, MAT 080/Modules 6-8								
White	60	6	47	25	12.97171	9	0.16389	0.25531
Black/AA	15	1	9	5				
Hispanic	3	0	9	3				
Other	12	1	2	1				
Cohort & Placement: Mixed Cohort, MAT 080/Modules 6-8								
White	6	0	3	1	18.70000	9	0.02787	1.01926
Black/AA	0	0	2	0				
Hispanic	0	2	1	0				
Other	3	0	0	0				

Table 27 continued

Chi-square test for final status by placement, cohort and race/ethnicity

	Final Status							
Race	Did Not Pass	Graduated	Passed	Still Enrolled	Chi-square	*df*	*p*	*Φ*
Cohort & Placement: Old Cohort, Above MAT 080/Module 8								
White	108	0	501	2	27.14699	9	0.00132	0.19166
Black/AA	16	1	43	2				
Hispanic	6	0	19	0				
Other	3	0	38	0				
Cohort & Placement: New Cohort, Above MAT 080/Module 8								
White	104	2	484	59	24.65355	9	0.00338	0.16203
Black/AA	29	2	61	15				
Hispanic	15	0	80	8				
Other	19	0	58	3				

Notes:

No Above MAT 080/Module 8 students exist in the mixed cohort

Table 28
Comparison of pass vs no pass (only) final statuses by placement, cohort, and race/ethnicity

Race	n	Pass %	*Z* (vs. White)	*p*	ES
Cohort & Placement: Old Cohort, MAT 050					
White	142	7.04%			
Black/AA	204	2.94%	1.78681	0.07397	0.09606
Hispanic	3	33.33%	-1.70196	0.08876	0.14134
Other	22	0.00%	1.28448	0.19897	0.10030
Cohort & Placement: New Cohort, MAT 050					
White	7	0.00%			
Black/AA	21	0.00%	NA	NA	NA
Hispanic	2	0.00%	NA	NA	NA
Other	3	0.00%	NA	NA	NA
Cohort & Placement: Mixed Cohort, MAT 050					
White	14	14.29%			
Black/AA	21	9.52%	0.43379	0.66444	0.07332
Hispanic	0	NA	NA	NA	NA
Other	0	NA	NA	NA	NA
Cohort & Placement: Old Cohort, MAT 060/Modules 1-3					
White	1731	14.44%			
Black/AA	1126	9.41%	3.97689	0.00007	0.07440
Hispanic	116	18.10%	-1.07880	0.28068	0.02510
Other	145	19.31%	-1.58480	0.11301	0.03659
Cohort & Placement: New Cohort, MAT 060/Modules 1-3					
White	752	12.37%			
Black/AA	591	6.94%	3.29568	0.00098	0.08993
Hispanic	82	12.20%	0.04493	0.96417	0.00156
Other	101	8.91%	1.00511	0.31484	0.03441
Cohort & Placement: Mixed Cohort, MAT 060/Modules 1-3					
White	203	24.14%			
Black/AA	151	11.92%	2.90228	0.00370	0.15425
Hispanic	19	36.84%	-1.21927	0.22274	0.08183
Other	21	23.81%	0.03349	0.97328	0.00224

Table 28 continued

Comparison of pass vs no pass (only) final statuses by placement, cohort, and race/ethnicity

Race	n	Pass %	*Z*	*p*	ES
Cohort & Placement: Old Cohort, MAT 070/Modules 4-5					
White	2722	36.15%			
Black/AA	598	24.58%	5.40463	6.49E-08	0.09380
Hispanic	144	35.42%	0.17852	0.85832	0.00333
Other	154	29.22%	1.74516	0.08096	0.03254
Cohort & Placement: New Cohort, MAT 070/Modules 4-5					
White	610	29.51%			
Black/AA	171	16.96%	3.27590	0.00105	0.11722
Hispanic	58	41.38%	-1.87579	0.06068	0.07258
Other	50	22.00%	1.12552	0.26037	0.04381
Cohort & Placement: Mixed Cohort, MAT 070/Modules 4-5					
White	164	32.32%			
Black/AA	55	27.27%	0.69966	0.48414	0.04728
Hispanic	17	29.41%	0.24435	0.80696	0.01816
Other	8	12.50%	1.17932	0.23827	0.08992
Cohort & Placement: Old Cohort, MAT 080/Modules 6-8					
White	492	54.88%			
Black/AA	105	40.00%	2.77083	0.00559	0.11340
Hispanic	26	57.69%	-0.28112	0.77862	0.01235
Other	33	54.55%	0.03717	0.97035	0.00162
Cohort & Placement: New Cohort, MAT 080/Modules 6-8					
White	107	43.93%			
Black/AA	24	37.50%	0.57504	0.56526	0.05024
Hispanic	12	75.00%	-2.04503	0.04085	0.18747
Other	14	14.29%	2.12449	0.03363	0.19314
Cohort & Placement: Mixed Cohort, MAT 080/Modules 6-8					
White	9	33.33%			
Black/AA	2	100.00%	-1.71270	0.08677	0.51640
Hispanic	1	100.00%	-1.29099	0.19671	0.40825
Other	3	0.00%	1.15470	0.24821	0.33333

Table 28 continued

Comparison of pass vs no pass (only) final statuses by placement, cohort, and race/ethnicity

Race	n	Pass %	*Z*	*p*	ES
Cohort & Placement: Old Cohort, Above MAT 080/Module 8					
White	609	82.27%			
Black/AA	59	72.88%	1.77023	0.07669	0.06849
Hispanic	25	76.00%	0.79958	0.42396	0.03176
Other	41	92.68%	-1.71570	0.08622	0.06730
Cohort & Placement: New Cohort, Above MAT 080/Module 8					
White	588	82.31%			
Black/AA	90	67.78%	3.23385	0.00122	0.12420
Hispanic	95	84.21%	-0.45243	0.65096	0.01731
Other	77	75.32%	1.48512	0.13751	0.05759

Notes:

No Above MAT 080/Module 8 students exist in the mixed cohort

Effect size calculated using Z/sqrt(n) method

Table 29
Mean number of modules completed by starting state

State	*M*	*SD*	ANOVA	*SS*	*df*	*MS*	*F*	*p*	eta^2
Chose 1 Module									
Module 1	0.580	0.496	Between	1.37900	7	0.19700	0.80600	0.58300	0.01196
Module 2	0.417	0.515	Within	113.87800	466	0.24400			
Module 3	0.569	0.499	Total	115.25700	473				
Module 4	0.529	0.504							
Module 5	0.604	0.491							
Module 6	0.545	0.501							
Module 7	0.667	0.516							
Module 8	0.700	0.463							
Module 1-R	0.700	0.483	Between	3.21700	7	0.46000	1.89900	0.07100	0.05465
Module 2-R	0.400	0.548	Within	55.64800	230	0.24200			
Module 3-R	0.640	0.490	Total	58.86500	237				
Module 4-R	0.323	0.475							
Module 5-R	0.506	0.503							
Module 6-R	0.581	0.499							
Module 7-R	0.750	0.500							
Module 8-R	0.683	0.471							
Chose 2 Modules									
Module 1	1.259	0.824	Between	31.95000	6	5.32500	7.08800	2.13E-07	0.04355
Module 2	0.785	0.870	Within	701.71900	934	0.75100			
Module 3	0.787	0.806	Total	733.66900	940				
Module 4	1.033	0.917							
Module 5	0.913	0.732							
Module 6	0.681	0.887							
Module 7	1.305	0.845							
Module 8	0.333	0.577							
Module 1-R	0.818	0.853	Between	15.31700	6	2.55300	3.85500	0.00096	0.06005
Module 2-R	0.862	0.953	Within	239.74500	362	0.66200			
Module 3-R	0.500	0.674	Total	255.06200	368				
Module 4-R	0.593	0.786							
Module 5-R	0.673	0.774							
Module 6-R	0.250	0.550							
Module 7-R	1.073	0.940							
Module 8-R	0.000	NA							

Table 29 continued
Mean number of modules completed by starting state

State	*M*	*SD*	ANOVA	*SS*	*df*	*MS*	*F*	*p*	eta^2
Chose 3 Modules									
Module 1	1.769	1.174	Between	213.59700	5	42.71900	32.47400	1.48E-32	0.03955
Module 2	0.848	1.017	Within	5186.94000	3943	1.31600			
Module 3	1.145	1.132	Total	5400.53700	3948				
Module 4	1.402	1.065							
Module 5	1.200	1.070							
Module 6	1.609	1.301							
Module 7	0.667	1.033							
Module 1-R	1.505	1.211	Between	55.27400	5	11.05500	9.19900	1.41E-08	0.04259
Module 2-R	0.844	1.019	Within	1242.58700	1034	1.20200			
Module 3-R	1.000	1.054	Total	1297.86100	1039				
Module 4-R	1.032	0.995							
Module 5-R	0.643	0.745							
Module 6-R	1.010	1.183							
Module 7-R	0.750	0.500							

Notes:
States Module 8 and Module 8-R removed from Chose 2 Modules ANOVA
States Modules 7, 8, 7-R, and 8-R removed from Chose 3 Modules ANOVA

Table 30
Tukey's HSD post-hoc test for mean number of modules completed

		99.9% Confidence Interval		
Start State Comparison	Mean Difference	LL	UL	*p*
Category: Chose 2 modules, Non-R states				
Module 1 vs. Module 2	-0.4740	-0.9282	-0.0198	0.0005
Module 1 vs. Module 3	-0.4720	-1.0524	0.1084	0.0170
Module 1 vs. Module 4	-0.2260	-0.5486	0.0966	0.0674
Module 1 vs. Module 5	-0.3460	-0.8235	0.1315	0.0514
Module 1 vs. Module 6	-0.5780	-1.1584	0.0024	0.0011
Module 1 vs. Module 7	0.0460	-0.3911	0.4831	0.9995
Module 2 vs. Module 3	0.0020	-0.6283	0.6323	0.9999
Module 2 vs. Module 4	0.2480	-0.1575	0.6535	0.1659
Module 2 vs. Module 5	0.1280	-0.4090	0.6650	0.9606
Module 2 vs. Module 6	-0.1040	-0.7343	0.5263	0.9941
Module 2 vs. Module 7	0.5200	0.0185	1.0215	0.0005
Module 3 vs. Module 4	0.2460	-0.2971	0.7891	0.5210
Module 3 vs. Module 5	0.1260	-0.5212	0.7732	0.9858
Module 3 vs. Module 6	-0.1060	-0.8325	0.6205	0.9970
Module 3 vs. Module 7	0.5180	-0.1001	1.1361	0.0121
Module 4 vs. Module 5	-0.1200	-0.5514	0.3114	0.9188
Module 4 vs. Module 6	-0.3520	-0.8951	0.1911	0.1171
Module 4 vs. Module 7	0.2720	-0.1143	0.6583	0.0648
Module 5 vs. Module 6	-0.2320	-0.8792	0.4152	0.7706
Module 5 vs. Module 7	0.3920	-0.1306	0.9146	0.0380
Module 6 vs. Module 7	0.6240	0.0059	1.2421	0.0009

Table 30 continued
Tukey's HSD post-hoc test for mean number of modules completed

Start State Comparison	Mean Difference	99.9% Confidence Interval		*p*
		LL	UL	
Category: Chose 2 modules, -R states				
Module 1-R vs. Module 2-R	0.0440	-0.8982	0.9862	0.9999
Module 1-R vs. Module 3-R	-0.3180	-1.5139	0.8779	0.9311
Module 1-R vs. Module 4-R	-0.2250	-0.9772	0.5272	0.8842
Module 1-R vs. Module 5-R	-0.1450	-1.0002	0.7102	0.9929
Module 1-R vs. Module 6-R	-0.5680	-1.5976	0.4616	0.2671
Module 1-R vs. Module 7-R	0.2550	-0.5857	1.0957	0.8771
Module 2-R vs. Module 3-R	-0.3620	-1.5059	0.7819	0.8536
Module 2-R vs. Module 4-R	-0.2690	-0.9353	0.3973	0.6477
Module 2-R vs. Module 5-R	-0.1890	-0.9698	0.5918	0.9557
Module 2-R vs. Module 6-R	-0.6120	-1.5806	0.3566	0.1328
Module 2-R vs. Module 7-R	0.2110	-0.5538	0.9758	0.9186
Module 3-R vs. Module 4-R	0.0930	-0.9002	1.0862	0.9997
Module 3-R vs. Module 5-R	0.1730	-0.9004	1.2464	0.9946
Module 3-R vs. Module 6-R	0.2500	-1.4669	0.9669	0.9804
Module 3-R vs. Module 7-R	0.5730	-0.4888	1.6348	0.2927
Module 4-R vs. Module 5-R	0.0800	-0.4563	0.6163	0.9965
Module 4-R vs. Module 6-R	-0.3430	-1.1281	0.4421	0.5563
Module 4-R vs. Module 7-R	0.4800	-0.0328	0.9928	0.0028
Module 5-R vs. Module 6-R	-0.4230	-1.3073	0.4613	0.4429
Module 5-R vs. Module 7-R	0.4000	-0.2547	1.0547	0.1615
Module 6-R vs. Module 7-R	0.8230	-0.0472	1.6932	0.0024

Table 30 continued

Tukey's HSD post-hoc test for mean number of modules completed

Start State Comparison	Mean Difference	99.9% Confidence Interval		p
		LL	UL	
Category: Chose 3 modules, Non-R states				
Module 1 vs. Module 2	-0.9210	-1.3219	-0.5201	0.0001
Module 1 vs. Module 3	-0.6240	-1.0700	-0.1780	0.0001
Module 1 vs. Module 4	-0.3670	-0.5312	-0.2028	0.0001
Module 1 vs. Module 5	-0.5690	-1.1655	0.0275	0.0021
Module 1 vs. Module 6	-0.1600	-0.4043	0.0843	0.0976
Module 2 vs. Module 3	0.2970	-0.2847	0.8787	0.3276
Module 2 vs. Module 4	0.5540	0.1460	0.9620	0.0001
Module 2 vs. Module 5	0.3520	-0.3518	1.0558	0.3513
Module 2 vs. Module 6	0.7610	0.3147	1.2073	0.0001
Module 3 vs. Module 4	0.2570	-0.1954	0.7094	0.2134
Module 3 vs. Module 5	0.0550	-0.6755	0.7855	0.9997
Module 3 vs. Module 6	0.4640	-0.0232	0.9512	0.0021
Module 4 vs. Module 5	-0.2020	-0.8033	0.3993	0.7666
Module 4 vs. Module 6	0.2070	-0.0489	0.4629	0.0167
Module 5 vs. Module 6	0.4090	-0.2190	1.0370	0.1011

Table 30 continued

Tukey's HSD post-hoc test for mean number of modules completed

Start State Comparison	Mean Difference	99.9% Confidence Interval LL	99.9% Confidence Interval UL	*p*
Category: Chose 3 modules, -R states				
Module 1-R vs. Module 2-R	-0.6610	-1.4727	0.1507	0.0153
Module 1-R vs. Module 3-R	-0.5050	-1.3675	0.3575	0.1825
Module 1-R vs. Module 4-R	-0.4730	-0.7950	-0.1510	0.0001
Module 1-R vs. Module 5-R	-0.8620	-2.0553	0.3313	0.0470
Module 1-R vs. Module 6-R	-0.4950	-0.8992	-0.0908	0.0001
Module 2-R vs. Module 3-R	0.1560	-0.9733	1.2853	0.9940
Module 2-R vs. Module 4-R	0.1880	-0.6090	0.9850	0.9363
Module 2-R vs. Module 5-R	-0.2010	-1.5994	1.1974	0.9928
Module 2-R vs. Module 6-R	0.1660	-0.6676	0.9996	0.9687
Module 3-R vs. Module 4-R	0.0320	-0.8166	0.8806	0.9999
Module 3-R vs. Module 5-R	-0.3570	-1.7855	1.0715	0.9196
Module 3-R vs. Module 6-R	0.0100	-0.8731	0.8931	0.9999
Module 4-R vs. Module 5-R	0.3890	-1.5724	0.7944	0.7803
Module 4-R vs. Module 6-R	-0.0220	-0.3958	0.3518	0.9999
Module 5-R vs. Module 6-R	0.3670	-0.8413	1.5753	0.8523

Notes:

Start states Module 8 and 8-R not used for chose 2 students (low sample size)

Start states Module 7, 8, 7-R and 8-R not used for chose 3 students (low sample size)

Table 31
Multiple measures vs other placements: All attempts

Placement	n	Success %	*Z*	*p*	ES
Course: MAT 110					
MM	7	85.71%	0.53482	0.59278	0.05801
Other	78	76.92%			
Course: MAT 115					
MM	9	88.89%	0.87469	0.38174	0.03547
Other	599	76.46%			
Course: MAT 121					
MM	9	44.44%	-2.26024	0.02381	0.11259
Other	394	76.90%			
Course: MAT 140					
MM	117	67.52%	-1.03487	0.30073	0.01881
Other	2909	71.91%			
Course: MAT 151					
MM	84	53.57%	-1.59042	0.11174	0.06297
Other	554	62.64%			
Course: MAT 161					
MM	384	52.08%	-6.65682	2.80E-11	0.12361
Other	2516	69.24%			

Notes:
Misplaced, Regress, and No Data placement students removed
Repeat (-R) states put back with Non-Repeat states due to low sample size
MAT 120 and MAT 175 had no MM students
Effect size calculated using Z/sqrt(n) method

Table 32
Multiple measures vs other placements: First attempt only

Placement	n	Success %	*Z*	*p*	ES
Course: MAT 110					
MM	7	85.71%	0.43989	0.66001	0.04858
Other	75	78.67%			
Course: MAT 115					
MM	9	88.89%	0.83583	0.40325	0.03492
Other	564	77.13%			
Course: MAT 121					
MM	8	50.00%	-1.91657	0.05529	0.09964
Other	362	78.45%			
Course: MAT 140					
MM	111	68.47%	-1.37304	0.16974	0.02662
Other	2549	74.30%			
Course: MAT 151					
MM	78	51.28%	-2.06130	0.03927	0.08508
Other	509	63.46%			
Course: MAT 161					
MM	351	53.56%	-6.65960	2.75E-11	0.13081
Other	2241	71.26%			

Notes:
Misplaced, Regress, and No Data placement students removed
Repeat (-R) states put back with Non-Repeat states due to low sample size
MAT 120 and MAT 175 had no MM students
Effect size calculated using Z/sqrt(n) method

Table 33
Evaluation of partial credit: Progression rates

	Ending State			
Start State	Module 1	Module 2	Module 3	MAT 070/Module 4+
MAT 060	2109 (46.32%)	0 (0.00%)	0 (0.00%)	2444 (53.68%)
Module 1/Chose 3	386 (19.75%)	465 (23.80%)	317 (16.22%)	786 (40.23%)
MAT 060-R	648 (70.90%)	0 (0.00%)	0 (0.00%)	266 (29.10%)
Module 1-R/Chose 3	84 (28.09%)	77 (25.75%)	41 (13.71%)	97 (32.44%)

	Ending State		
Start State	Module 4	Module 5	MAT 080/Module 6+
MAT 070	2902 (45.25%)	0 (0.00%)	3511 (54.75%)
Module 4/Chose 3	376 (29.72%)	194 (15.34%)	695 (54.94%)
MAT 070-R	1235 (67.01%)	0 (0.00%)	608 (32.99%)
Module 4-R/Chose 3	197 (41.39%)	98 (20.59%)	181 (38.03%)

	Ending State			
Start State	Module 6	Module 7	Module 8	Complete Dev Math
MAT 080	1076 (50.85%)	0 (0.00%)	0 (0.00%)	1040 (49.15%)
Module 6/Chose 3	134 (31.75%)	69 (16.35%)	47 (11.14%)	172 (40.76%)
MAT 080-R	514 (67.37%)	0 (0.00%)	0 (0.00%)	249 (32.63%)
Module 6-R/Chose 3	95 (49.74%)	36 (18.85%)	23 (12.04%)	37 (19.37%)

Notes:
Comparison set as described in Chapter 4 for Research Question 5: Analysis

Table 34
Evaluation of partial credit: Modules passed

Start State	*M*	*SD*	*n*	*t*	*df*	*p*	*d*
MAT 060	1.610	1.496	4553	-4.59586	6505	2.20E-06	0.05697
Module 1/Chose 3	1.769	1.174	1954				
MAT 060-R	0.873	1.363	914	-7.58789	1211	3.23E-14	0.21787
Module 1-R/Chose 3	1.505	1.211	299				

Start State	*M*	*SD*	*n*	*t*	*df*	*p*	*d*
MAT 070	1.095	0.996	6413	-5.64384	7676	8.61E-09	0.06441
Module 4/Chose 3	1.252	0.885	1265				
MAT 070-R	0.660	0.941	1843	-6.60202	2317	2.51E-11	0.13710
Module 4-R/Chose 3	0.966	0.891	476				

Start State	*M*	*SD*	*n*	*t*	*df*	*p*	*d*
MAT 080	1.474	1.500	2116	-1.89517	2536	0.02909	0.03762
Module 6/Chose 3	1.609	1.301	422				
MAT 080-R	0.979	1.408	763	-0.31116	952	0.37787	0.01007
Module 6-R/Chose 3	1.010	1.183	191				

Notes:
Comparison set as described in Chapter 4 for Research Question 5: Analysis