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Most students in U.S. universities are required to take a collection of core courses regardless of their degree or major. These courses are known as "general education" courses. The general education requirements typically include at least one mathematics course. Unfortunately each year hundreds of thousands of students in the US do not succeed in these general education mathematics courses causing them to act as a barrier to degree completion. Low student success rates in these courses are pervasive, and it is well documented that the U.S. needs to improve student success and retention in general education mathematics courses.

In this paper, we compare the impact of a new instructional style on student retention and success in three general education mathematics courses. The new instructional style, that we have dubbed the Memphis Mathematics Method (MMM), is a blended learning instructional model, developed in conjunction with the National Center for Academic Transformation (NCAT). Our control consists of conventional lectures using identical syllabuses. The data contains 12,261enrollments in College Algebra, Foundations of Mathematics, and Elementary Calculus over the Fall 2007 to Spring 2010 terms at the University of Memphis.

Our results show the MMM was positive and significant for raising success rates particularly in Elementary Calculus. In addition, the results show the MMM as a potential vehicle for closing the achievement gap between black and white students in such courses.

1 INTRODUCTION

In the U.S., many students who pursue a postsecondary baccalaureate degree are required to complete at least one general education mathematics course. Low student success rates in these courses are pervasive, and it is well documented that the U.S. needs to improve student success and retention in general mathematics. For example, Haver, Small, Ellington, Edwards, Kays and Haddock (2007) report that nationwide, more than 45% of students enrolled in College Algebra courses either withdraw (W) or receive a non-passing grade of a D or F each year. The Conference Board of the Mathematical Sciences, an umbrella organization of 16 American Professional Societies, reported that across the U.S. approximately 250,000 students annually enrol in a College Algebra course at four-year colleges and universities across the U.S. (Lutzer, Rodi, Kirkman and Maxwell, 2007). This means that a minimum of 110,000 students withdraw or receive a non-passing grade of D or F each year at our nation's four-year colleges and universities. These high failure and withdrawal rates have been attributed to various factors such as personal student attributes including socioeconomic status background or special education needs (Eskew and Faley, 1988, Wagner and Blackorby, 1996, Gamoran, Porter, Smithson and White, 1997), lack of academic preparation, lack of student effort and knowledge of effective study skills (Conley, 2007), and lack of alignment between high school completion and college readiness (Conley, Aspengren, Stout and Veach, 2006). Because the high rates of failure and withdrawal represent such a large number of students, efforts to improve student learning and success rates in these courses are crucial.

National recognition of the poor success rates in general education mathematics courses has resulted in vigorous debate and a series of proposed reform models over the past two decades, typically involving either as curricular reform or delivery reform. Particular attention has been paid to reforming the College Algebra and Calculus curriculum and pedagogies. The Mathematical Association of America's Committee on Undergraduate Programs in Mathematics (CUPM), consisting of a group of 27 college and university faculty members in mathematics and statistics, recommends that College Algebra focus more on real-world problems involving modelling and applications (2004). CUPM cites the use of "computer technology to support problem solving and to promote understanding" as one of six recommendations when developing a curriculum for postsecondary mathematics courses (2004, p.22). Technology focused reforms have included attempts to change instructional delivery methods by training students to use technology to solve problems (Lavicza, 2009; Heid and Edwards, 2001; Smith, 2007), using technology as an instructional tool (Peschke, 2009; Judson and Sawada, 2002; Caldwell, 2007; Fies and Marshall, 2006), or using a technology based assessment system (Zerr, 2007; Nguyen, Hsieh and Allen, 2006; Vanlehn, Lynch, Schulze, Shapiro, Shelby and Taylor, 2005).

In this paper, we report results comparing the impact of the Memphis Mathematics Method (MMM), a highly structured blended learning instructional model that incorporates the use of technology with short lectures, to the traditional lecture only teaching method on student performance and retention in general education mathematics courses at the University of Memphis (UM). The MMM was developed in alignment with the National Center for Academic Transformation's (NCAT) Emporium model using fixed-attendance (http://www.thencat.org/R2R/AcadPrac/CM/MathEmpFAQ.htm) where students are required to attend a fixed amount of laboratory hours throughout the semester. The comparison includes a total of 12,261 enrolments in College Algebra, Foundations of Mathematics, and Elementary Calculus from Fall 2007 to Spring 2010. Results indicate that the MMM is effective in increasing student achievement and retention. This study adds to the existing body of knowledge by providing a large-scale quantitative analysis on the effectiveness of the fixed-attendance NCAT Emporium model. This highly structured blended learning instructional model incorporates the use of technology with short lectures in the undergraduate classroom. In conjunction with the online practice, the MMM offers students individual attention by the instructor of the course.

2 BACKGROUND

There is a general belief that instructional delivery methods directly affect the students' learning environment and hence indirectly affect student achievement. For example, an environment in which students actively participate and engage in learning likely creates rich opportunities for deep learning of mathematics (Schoenfeld, 1994; Henningsen and Stein, 1997). Moreover, there is mounting evidence that integrating technology in undergraduate instruction positively associates with student achievement (Alldredge and Brown, 2006; O'Callaghan, 1998) and attitudes (Hauk and Segalla, 2005; Cretchley, Harman, Ellerton and Fogarty, 2000). Similarly, research confirms that computer instruction may be as or more effective than traditional classroom instruction due to the self-paced and individualized nature of the instruction (Means, Olson and Singh, 1995; Barrow, Markman and Rouse, 2009; Liao, 2007).

Considering the positive results found in the literature regarding teaching with technology, researchers in the Department of Mathematical Sciences at UM decided to redesign the manner in which the general education mathematics courses are taught at UM. The MMM design aims to reflect the current understanding of the effective use of technology in the classroom both to create an active blended learning environment that is aligned with cognitive principles and to allow for more effective management of the classroom and instructor time. In addition, utilizing the features of the MyMathLab software, the MMM aims to more effectively engage students with mathematics in a non-threatening manner that bolsters student success and confidence. The Framework section below describes in more detail the principles that guided the design of the MMM.

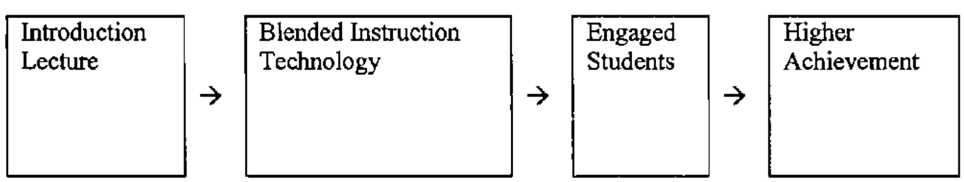

Figure 1: Framework Model Diagram

3 FRAMEWORK

Figure 1 represents the conceptual framework driving the development of the MMM.

In general, technology is believed to have a positive impact on student learning in mathematics. Many studies conducted in K–12 environments have reported significant gains in learning or learning speed (Koedinger, Anderson, Hadley and Mark 1997; Fletcher, 2003; Anderson, Corbett, Koedinger and Pellitier, 1995) when technology is incorporated into instruction. At the postsecondary level, studies have shown an increase in student success and learning when technology is employed in the classroom (O'Callaghan, 1998; Yaron, Cuadros and Karabinos, 2005; VanLehn, Lynch, Schulze, Shapiro and Shelby, 2005; Ringenberg and VanLehn, 2006; Matsuda and VanLehn, 2005).

The implementation of technology through blended instructional strategy aligns with a variety of theoretical orientations that appeal to cognitive flexibility (Spiro, Feltovich, Jacobson and Coulson, 1992), integrating abstract and concrete representations of concepts (Pashler, Bain,Bottge, Graesser, Koedinger and McDaniel, 2007), embodied cognition (De Vega, Glenberg and Graesser, 2008), combining inquiry and knowledge building (Mayer, 2003), and other perspectives in the constructivist tradition. For example, technology in a post-secondary mathematics classroom may allow students the flexibility of exploring concepts at their own pace, may provide a tool with which students can visualize and conceptualize concepts in a different setting, and may provide students with concrete representations of the mathematical concepts being taught. As such, integrating technology in the general education mathematics undergraduate classroom may then, in turn, promote student engagement, participation, and inquiry in the constructivist spirit.

Recently, researchers have begun to make recommendations as to the appropriate proportion of student-centred and teacher-guided instruction (Chi, Siler, Jeong and Hausmann, 2001). For example, Mayer (2004) suggests that a blend of instructional methods be used rather than pure student-centred discovery. He states, "In many ways, guided discovery appears to offer the best method for promoting constructivist learning. The challenge of teaching by guided discovery is to know how much and what kind of guidance to provide and to know how to specify the desired outcome of learning."(Mayer, 2004, p.17) Using technology in the classroom can create a student-centred, active learning environment (White and Frederiksen, 1998; National Research Council, 2000; Fletcher, 2003). Computers and tutoring software are particularly effective tools in increasing learning (Sandholtz, Ringstaff and Dwyer, 1997; Lowther, Ross and Morrison, 2003; Smaldino, Lowther and Russell, 2008). This evidence suggests that a blended instructional method - technology coupled with guided lecture - may be ideal for increasing learning and achievement.

The MMM utilizes the MyMathLab software to deliver the technology component of the general education math courses. MyMathLab provides students with instant feedback for their work which research has shown leads to improved student achievement (Brooks, 1997; de La Beaujardiere, Cavallo, Hasler, Mitchell, O'Handley, Shiri and White, 1997; Khan, 1997). In addition, MyMathLab offers student aid features that align with elements identified in the literature as fostering increased student learning and understanding. These five learning aids are: (1) step-by-step worked solution of a similar problem, (2) video example, (3) just-in-time, (4) view an example, and (5) ask my instructor. First, the "step-by-step worked solution of a similar problem" tool can help students scaffold the content being covered in the problem. As pointed out by VanLehn (2006), multi-step problem-solving tutoring promotes a deep understanding of content in a broad variety of intelligent tutoring systems as well as more conventional computer-based training. Second, the multimedia tool "video example" capitalizes on the advantages of multiple media and modalities in improving learning and memory (Mayer, 2005; Pashler et al., 2007). Third, the availability of the electronic textbook while working through a problem allows a learner to access information "just-in-time" for achieving learner goals during problem solving (Rouet, 2006). This retrospective learning strategy allows students to read text when it is needed, which has been shown to increase learning of difficult content (Bransford and Schwartz, 1999). Fourth, "view an example" guides the student through example problems with solutions, a technique that is compatible to the research of Sweller on worked-out examples (Sweller and Chandler, 1994). Fifth, the "ask my instructor" aid allows students to directly email the instructor for help. The email message contains the exact problem the student is having trouble with, thus allowing an instructor to closely monitor progress and success by students in need of help. This conversational aid is comparable to intelligent tutoring systems that help students learn by holding a conversation in natural language (VanLehn, Gaesser, Jackson, Jordan, Olney and Rose, 2007). Although conversing about mathematics can be difficult in an email setting due to the inherent problems with symbolism, because MyMathLab directly emails the instructor the problem the students is asking about as well as the student's work with the problem thus far, potential difficulties with symbolism are mediated in the MyMathLab system. Collectively, these tools define MyMathLab as interactive content delivery software that aligns with cognitive principles of learning and curriculum in a blended instructional setting.

MMM is designed to reflect the current understanding of the effective use of technology in the classroom both to create an active blended learning environment that is aligned with cognitive principles and to allow for more effective management of the classroom and instructor time. In addition, utilizing the features of MyMathLab software, MMM aims to more effectively engage students with mathematics in a non-threatening manner that bolsters student success and confidence. Overall, the MMM aims to effectively engage students with mathematics in a non-threatening manner that bolsters student success and confidence.

4 THE MEMPHIS MATHEMATICS METHOD

The design of MMM aims to strike a balance between two integral theoretical constructs identified in the literature as effective in helping students achieve learning success: (1) the blended learning environment, and (2) the use of technology as an instructional tool.

The MMM substitutes traditional lecture-style instruction with a brief introduction of a topic followed by a laboratory session requiring students to complete classroom-based assignments using MyMathLab software. The MyMathLab software was selected because it offers student aid features that align with elements identified in the literature as fostering increased student learning and understanding. As the software is straightforward and simple to use, students are not provided with any external training of how to interact with the software. Instead, students begin working on MyMathLab directly during the first in-class assignment. The assignments consist of lists of problems, some open ended but mostly multiple-choice, that students can open and complete one by one. Students may also watch video tutorials to learn how to use the system and instructors and teaching assistants are present in order to ensure every student is up to speed with the technology.

Instructors employing MMM begin each class with a 25-minute lecture followed by a problem-solving session using MyMathLab. During the short lecture, instructors introduce basic concepts and provide examples that emphasize the use of mathematical techniques to solve problems motivated by other sciences. Each lecture contains a list of objectives, a few illustrative examples, and mathematical problems for discussion during the presentation. The lectures are guided by a PowerPoint presentation that contains succinct information about the topics of the day. Illustrative examples are included in the presentation and subsequently solved by the instructor directly on the board.

The remaining class time is dedicated to solving problems within the MyMathLab software. The problems are chosen by the instructor and are a combination of review questions from the previous class periods and problems directly related to the new concepts presented in the introductory lecture. Most problems require students to make pencil-and-paper computations. There is an expectation for students to finish the class assignment during the time allocated for problem solving. Students who do not complete their assignments during regular class time have the option of completing the assignment at home; however, they receive reduced credit (1/3 the point value) for problems solved in this fashion. The instructor and an assistant, typically an advanced undergraduate student, are available during the class period to provide individual help and answer technical questions. As students solve problems on MyMathLab, the system provides instant feedback as to whether the students correctly answered the problem or not. All help features of the software are disabled for class assignments in order to incentivize students to communicate, discuss, and ask for help from the assistant and instructor. In this manner, students are able to build confidence operating in the lab environment where human support is available. This differs from a traditional classroom is that student groups receive feedback on the correctness of their solutions immediately as they work the problems in class. This helps to avoid students spending the long periods of time thinking they are correct, when in fact they are only further embedding incorrect ideas into their thinking. The MMM thus drastically differs from a traditional general education mathematics classroom since interactive problem solving sessions are not common and often not feasible is large general education mathematics courses.

Over the course of a 15-week semester, students log 30 hours of class time practicing problems on MyMathLab. Because of the extensive amount of time students spend on MyMathLab doing routine practice problems, students become fluent in the procedures needed to solve the problems. MyMathLab offers students an extensive practice platform to exercise their mathematical understanding and skills. In addition to its use as an instructional tool, instructors use the MyMathLab learning environment for course management and grading. Instructors can course manage by sending emails, uploading PowerPoint materials for students to view, uploading other pertinent information for the course, and using the built in grade sheet and roster. As instructors create assignments in MyMathLab, the instructors can choose from a question bank consisting of multiple choice and open-ended questions. In addition, instructors may submit their own questions with a solution for the system to use to grade. Multiple choice questions are graded as right or wrong by the system and open ended questions are referred back to the instructor to grade.

As stated above, the MyMathLab system provides conceptual and multimedia aids for students to use during their homework such as step-by-step instruction on similar problems, video examples, a worked-out example, electronic textbook access, and email to the instructor. The instructor on an assignment-by-assignment basis controls access to these features, thus instructors may limit student access to certain aids for particular assignments if they see fit. Final grades are computed as a weighted sum of all the points earned throughout the semester, including attendance, in-class lab assignments, tests, quizzes, and a final exam. Students complete proctored tests and the final exam online that consist of open-ended questions only (no multiple choice) in the instructional lab.

In contrast to the MMM, the conventional teaching method used traditional lecture - i.e., instructors lecture for the entire class period and work examples on the board in order for the students to see the applications. It is important to note that the conventionally taught sections and the MMM sections of the same course used the same identical curriculum delivered over the same time period. The MMM thus can be viewed as an innovation in teaching but not an innovation in curriculum.

5 DATA AND METHODS

The MMM intervention was piloted at UM in 2007 in a specialized Developmental Studies Program in Mathematics (DSPM) College Algebra course, which combined a remedial Intermediate Algebra course with a regular College Algebra course. Students were eligible for the DSPM course only if their American College Testing (ACT) test to assess college readiness scores would have required them to take remedial Intermediate Algebra. Students with ACT Math sub-scores of 18 or 19 were eligible for the DSPM courses.

Based on positive student outcomes during the initial pilot, UM expanded the MMM in 2008 to regular sections of College Algebra (non-DSPM); regular and DSPM sections of Foundations of Mathematics; and regular sections of Elementary Calculus. Instructors in both DSPM and regular MMM-taught sections reported anecdotal evidence of greater student engagement.

This study includes data from the Fall 2007 semester to the Spring 2010 semester. Summer sections were deemed sufficiently different from others that they were excluded from the analysis. There were 12,261 enrolments in the sections across the three courses. Of these, 10,667 enrolments were in regular sections while 1,594 enrolments were in DSPM sections.

College Algebra at UM covers basic algebraic tools and concepts with an emphasis on developing computational skills necessary for success in subsequent mathematics courses. During the course of the study, there were 4,911 enrolments in this course. Of these, 3,747 were taught in a conventional setting, of which 156 enrolments were in DSPM sections, and 3,591 were in regular sections. A total of 1,059 enrolments were in DSPM sections taught using the MMM and 105 enrolments were in regular sections taught using the MMM.

The Foundations of Mathematics course provides instruction in basic logic and problem-solving skills. Students who enrol in this course are typically non-STEM majors who choose this course to fulfil their general education requirement. From Fall 2007 to Spring 2010, there were 3,986 enrolments in this course. From Fall 2007 to Spring 2010, there were 4,085 enrolments in this course. Of these, 3,604 were taught traditionally, of which 263 enrolments were in DSPM sections, and 3,341 were in regular sections. A total of 116 enrolments were in DSPM sections taught using the MMM and 365 enrolments were in regular sections taught using the MMM.

Elementary Calculus introduces the tools of differential calculus with emphasis on solving problems motivated by the social and life sciences, economics, and business. From Fall 2007 to Spring 2010, there were a total of 3,207 enrolments in this course. Throughout the duration of this study, 2,780 enrolments were taught traditionally, and 485 were taught using MMM. Since completing College Algebra or having a sufficiently high ACT or Scholastic Aptitude Test (SAT) score were prerequisites for Elementary Calculus, there were no remedial sections of Elementary Calculus offered. Table 1 summarizes the breakdown of number of students receiving traditional or using the MMM by course.

	Traditional	MMM	DSPM-Traditional	DSPM-MMM
Foundations of Mathematics	3,341	365	263	116
College Algebra	3,591	105	156	1,059
Elementary Calculus	2,780	485		

Table 1 Cross tabulates for course by teaching method

The study uses data containing information about student characteristics, student performance, and teaching methodology. Data were gathered for all students who were enrolled in the courses at the end of the first week of classes in each semester.

Student Assignment

Students were free to sign up for any section of each course that they wanted to attend. Therefore, since students were not randomly assigned to the different instructional conditions, the study results cannot be interpreted as causal. In particular, bias may be present due to the type of teaching conditions offered at a given time in a given semester courses. For example, the regular sections of all three courses were contemporaneously offered using the traditional teaching method and the MMM teaching method each semester of data collection. This would thus allow for students to choose a method explicitly based on their preference. However, for the DSPM sections of both Foundations of Mathematics and College Algebra only one type of teaching condition was offered in a given semester. In other words, in a given semester all DSPM courses were either all taught using the MMM or all taught traditionally. As such, differences between the traditional and MMM sections of regular courses may be ascribed to explicit selection bias created by student being able to self-select into a teaching modality while differences between the traditional and MMM sections of the DSPM courses must be ascribed to changes in the student body over time.

In order to test whether the non-random assignment created selection bias i.e., there were significant differences between the student profiles being taught using the conventional method and the student profiles being taught by the MMM, we performed a Hoteling T^2 tests for equality of group means on student characteristics (gender and race) and student prior math knowledge (student ACT Math score) for each course type (Foundations, Foundations DSPM, College Algebra, College Algebra DSPM, and Elementary Calculus). Our results indicate that in the case of regular College Algebra and Elementary Calculus the student profiles in the conventional and the MMM do not differ. However, the student profiles in regular Foundations and the DSPM courses differ across teaching modality. Some of these differences might be attributed to the implementation and pilot of the DSPM College Algebra course. For example, for this course, students with low ACT scores were encouraged to enrol in the MMM methodology during the pilot semester. In order to ensure that we control for these differences while drawing comparisons between the MMM and traditional teaching, we employ the use of statistical regression techniques. Using regression and including gender, race, and prior achievement as controls, we can then draw comparisons between teaching methods while holding constant these other factors.

Dependent variables.

To gauge student success in the three courses, we define an indicator variable "success" coded as 1 if a student obtains a grade of A, B, or C and 0 otherwise (meaning they either withdrew or obtained a D or F grade). The variable success thus combines the effects of changes in pass rate and changes in dropout rate.

In addition, we are interested in separately determining the effects of the MMM pedagogy on dropout rates. We define an indicator variable "dropout" coded as 1 if a student withdrew from the course and 0 if a student completed the course. Success and dropout serve as our dependent variables in this study.

Independent variables.

We include the student's gender, the student's racial/ethnic background, and the student's prior mathematics knowledge as measured by their ACT math score, as three independent variables in the analysis. Student's racial/ethnic background is coded as White, Black, Hispanic, or Other though we only include black and white racial categories in our analyses since the other racial categories have insufficient numbers of allow valid inference (Hispanic $N = 210$ and Other $N = 310$). In addition, we control for whether a student is repeating the course and define an indicator variable "redo" coded as 1 if a student has attempted the course before and 0 if this is their first attempt. Finally, an indicator variable for whether a student was exposed to the traditional or to the MMM pedagogy is included in the analysis. Table 2 provides the descriptive statistics.

Variables	N	Mean	S. D.	Min	Max
Independent Variables					
ACT Math Score	10258	19.42	3.81	9	35
Redo	12261	0.14	0.35	0	1
Female	12261	0.59	0.49	0	1
Race					
White	6,032	49%			
Black	5,343	44%			
Hispanic	210	2%			
Other	310	3%			
Undeclared	366	3%			
Teaching Method					
Traditional	9,712	79%			
MMM	955	8%			
DSPM - Traditional	419	3%			
DSPM - MMM	1,175	10%			
Dependent Variables					
Dropout	12261	0.13	0.34	0	1
Success	12261	0.54	0.50	0	1

Table 2 Descriptive Statistics of the Variables

Regression Estimation approach.

To estimate the effects of MMM on student success and dropout rates in these courses, we fit a total of 12 regressions – three additive regression models for remedial courses, three interactive models for remedial courses, three additive models for non-remedial courses, and three interactive models for non-remedial courses.

To model the success rate and the dropout rate, we first estimate a set of additive models. Specifically, for both DSPM and regular courses, we fit logistic regressions for each of the three courses separately. Thus, we estimate the following:

$$\text{logit}(p_i) = \ln\left(\frac{p_i}{1-p_i}\right) = a + X_{1i}\beta_1 + X_{2i}\beta_2 + u_i$$

where p_i is the probability of student i succeeding or dropping out, a is a constant, X_{1i} is a vector of observed student i characteristics (gender, racial/ethnic background, ACT score, and redo), β_1 is the associated coefficient vector, X_{2i} is a dummy variable for whether student i was exposed to the MMM pedagogy, β_2 is its associated coefficient, and u_i is the error term. Therefore, the β coefficient vectors are interpreted as the additive effects on the log of the odds ratio.

Additionally, we explore modelling success and dropout by fitting a model with interactions of the following form:

$$\text{logit}(p_i) = \ln\left(\frac{p_i}{1-p_i}\right) = a + X_{1i}\beta_1 + X_{2i}\beta_2 + X_{3i}X_{2i}\beta_3 + u_i$$

where p_i is either the probability of student i succeeding or dropping out, a is a constant, X_{1i} is a vector of observed student i characteristics (gender, racial/ethnic background, ACT score, and redo), β_1 is the associated coefficient vector, X_{2i} is a dummy variable for whether student i was exposed to the MMM pedagogy, β_2 is the associated coefficient, X_{3i} is the indicator for whether student i is black, β_3 is the associated coefficient vector for the interaction term, and u_i is the error term..

6 RESULTS

Descriptive results.

Table 2 illustrates that of the 12,261 enrolments only 6,092 succeeded in the course reflecting a 54% success rate over the three courses. Of these 12,261 enrolments, 1,621 (13%) ended when the student dropped out of the course.

To begin exploring whether the MMM is effective in increasing student success and retention in core general education mathematics courses, we first examine descriptive breakdowns of success rates and dropout rates by teaching pedagogy. Table 3 presents the percentage of students that succeed and the percentage of students that withdraw for each course over the study period. Overall, the table illustrates that students in MMM classrooms dropout less and perform better.

	Foundations of Mathematics				College Algebra				Elementary Calculus	
	Trad	MMM	DSPM-Trad	DSPM-MMM	Trad	MMM	DSPM-Trad	DSPM-MMM	Trad	MMM
Succeed	54%	50%	55%	57%	53%	54%	57%	61%	49%	72%
Fail	33%	41%	34%	34%	34%	36%	30%	29%	33%	20%
Dropout	13%	9%	11%	9%	13%	10%	13%	10%	18%	8%

Table 3 Cross tabulates of percentage of students succeeding or dropping out for each course

Students in Elementary Calculus succeed at a rate of 72% in MMM courses compared to only 49% for traditionally taught courses. For every course, the percentage of students who dropped out from the MMM classes is lower than in the traditional classes. For example, 13% of students in traditional College Algebra dropped out while only 10% withdrew from the equivalent MMM courses. These results suggest that MMM instruction is successful in increasing retention and student success.

In Table 4, we compare the percentage breakdown of student performance and retention for black and white students for each course, and see that racial disparities in performance seem to be greatly reduced in the MMM classes.

	Foundations of Mathematics				College Algebra				Elementary Calculus	
	Trad	MMM	DSPM-Trad	DSPM-MMM	Trad	MMM	DSPM-Trad	DSPM-MMM	Trad	MMM
White										
Succeed	63%	59%	65%	63%	61%	60%	80%	66%	58%	69%
Dropout	12%	6%	10%	13%	12%	9%	6%	9%	15%	9%
Black										
Succeed	43%	40%	50%	55%	43%	44%	44%	59%	36%	75%
Dropout	14%	11%	12%	6%	13%	13%	17%	10%	22%	6%

Table 4 Cross tabulates of percentage of students succeeding or dropping out for each course by race

For example, in DSPM College Algebra, black students succeed at a rate of 44% when taught using traditional pedagogy compared to a success rate of 59% when using MMM. In Elementary Calculus, black students succeed at a rate of 36% while being taught traditionally and 75% with the MMM. This difference is staggering.

In DSPM courses, black students in Foundations of Mathematics dropout at a rate of 6% for the MMM method compared to a rate of 12% for traditional teaching. In DSPM College Algebra, these students dropout at a rate of 17% while being taught traditionally and only 10% while being taught with the MMM. Again, this differential improvement in percentages is large thus suggesting that the MMM is particularly effective with black students.

Regression Estimation results

We performed a complete case analysis and drop 2,763 enrolments (approximately 22.5% of the sample) for the regression analysis. The dropped enrolments are either missing racial/ethnic information or an ACT Math score. Approximately 2,000 enrolments are missing information on ACT Math score accounting for the majority of the information in the data set. As a result, our complete case sample is 9,498 enrolments to be included in the analysis.

The regression output is illustrated in Tables 5 and 6. Although both models (1) and (2) were estimated, we here present only the results of model (2). The additive model (model 1) results were consistent with those of the interactive model (model 2), however, due to the findings from Table 4 suggesting that Black students may particularly benefit from the MMM, the interactive model more accurately captures these data. As a sensitivity analysis, we also estimated models with student gender interacting with teaching methodology. None of the interaction terms were significant. Therefore, we only report the results for the estimation of the models including race and teaching methodology interactions. Table 5 presents the results estimating the success rate for each course while Table 6 presents the results estimating the dropout rate for each course. We perform a Hosmer-Lemeshow goodness of fit test (Hosmer and Lemeshow, 2000) for each of estimated models to test the validity of our models. We find that all but one, success regression for Foundations of Mathematics, of our models fit the data well. To explore why our model was not a good fit for the Foundations of Mathematics course, we explored whether there was a time effect. We ran a regression including an interaction of time with prior ACT score of the students enrolled during each semester in order to see if the quality of student within a semester provided the extra control for the model to be a good fit. As a result of this exploration, we found that in fact time was a determining factor for this course. Although the model including a time control was a better fit, the results of the coefficients and significance levels remained the same and thus are not presented separately.

Success

Consistent patterns emerge across all three courses targeting regular students. Female students in each course have a higher chance at succeeding than their male counterparts. The higher a student's ACT score the higher the likelihood of succeeding in the course. We find that students who were retaking a course have significantly lower odds of succeeding compared to those taking a course for the first time in College Algebra and Foundations regular courses.

	Regular Sections			DSPM Sections	
Variables	Foundations	Algebra	Calculus	Foundations	Algebra
Female	1.148	1.362**	1.479**	1.983*	1.350*
	(0.118)	(0.000)	(0.000)	(0.019)	(0.033)
Redo	0.665**	0.373**	0.890	1.056	0.702
	(0.001)	(0.000)	(0.313)	(0.906)	(0.113)
Black	0.612**	0.702**	0.498**	0.812	0.303**
	(0.000)	(0.000)	(0.000)	(0.524)	(0.006)
MMM	1.035	1.235	1.793**	1.072	0.517
	(0.862)	(0.582)	(0.000)	(0.867)	(0.100)
MMM & Black	1.117	1.015	4.866**	1.080	2.794*
	(0.689)	(0.977)	(0.000)	(0.886)	(0.027)
ACT Math	1.124**	1.166**	1.106**	1.198*	1.154**
	(0.000)	(0.000)	(0.000)	(0.043)	(0.007)
Constant	0.160**	0.064**	0.127**	0.044*	0.276
	(0.000)	(0.000)	(0.000)	(0.046)	(0.201)
Observations	2,860	2,929	2,452	303	954
Hosmer-Lemeshow χ^2	17.52	5.024	1.318	7.105	6.945
Prob > χ^2	0.0251	0.755	0.995	0.525	0.543
Robust p-value in parentheses: ** p<0.01, * p<0.05					

Table 5 Logistic Regression of Success

Table 5 results indicate that the MMM teaching pedagogy is significantly effective in increasing the odds of success in one of the three courses. In Calculus, students exposed to the MMM have 79% higher odds of succeeding than those in traditional Calculus. Furthermore, the results show that black students received an added benefit when being taught by the MMM. More specifically, black students instructed via MMM have 771% (computed as 1.79×4.866 - 1) higher odds of succeeding than Black students receiving traditional instruction. The effect sizes (average marginal effects) for the MMM in Elementary Calculus are 26% overall for all students and 47% for Black students only.

Columns 4 and 5 of Table 5 illustrate the success regression results for DSPM students only. As with the regular student population, female students have a higher chance of succeeding, as do students with higher ACT scores. We see that the MMM method is not statistically significant in increasing student success rates in either DSPM College Algebra or DSPM Foundations.

Dropout

Table 6 shows the logistic regression results for dropout. Female students have a lower probability (30% lower odds) of dropping out of Calculus compared to their male counterparts.

	Regular Sections			DSPM Sections	
Variables	Foundations	Algebra	Calculus	Foundations	Algebra
Female	0.902	0.832	0.706**	0.681	0.825
	(0.430)	(0.124)	(0.004)	(0.367)	(0.397)
ACT Math	0.929**	0.884**	0.935**	0.789	0.915
	(0.000)	(0.000)	(0.000)	(0.073)	(0.312)
Redo	1.277	1.134	0.695*	1.746	1.014
	(0.142)	(0.435)	(0.022)	(0.374)	(0.969)
Black	0.918	0.703**	1.375*	0.776	1.956
	(0.545)	(0.009)	(0.019)	(0.648)	(0.328)
MMM	0.510*	0.208	0.536*	1.527	1.189
	(0.073)	(0.128)	(0.016)	(0.495)	(0.790)
Black & MMM	1.724	5.065	0.388*	0.381	0.603
	(0.249)	(0.162)	(0.049)	(0.288)	(0.491)
Constant	0.557	1.770	0.862	7.081	0.377
	(0.168)	(0.206)	(0.707)	(0.375)	(0.553)
Observations	2,860	2,929	2,452	303	954
Hosmer-Lemeshow χ^2	9.290	8.514	7.898	7.560	7.780
Prob > χ^2	0.318	0.385	0.443	0.478	0.455
Robust p-value in parentheses: ** p<0.01, * p<0.05					

Table 6 Logistic Regression of Dropout

We find a strong ACT score effect illustrating that students with higher ACT scores have lower odds of dropping out in all courses. Students who are retaking a course are more likely to persist in Calculus with 31% lower odds of dropping out.

Black students in College Algebra have 30% lower odds of dropping out compared to white students. The MMM is positive and significant for students taking Calculus and Foundations. Calculus students in the MMM are about 47% lower odds of dropping out with respect to traditionally taught students while the Foundations students are at 49% lower odds of dropping out. The effect size of taking Elementary Calculus students using the MMM is approximately 9% for all students and 15% for black students only. These positive finding provides evidence that the MMM is effective in increasing retention.

7 DISCUSSION AND CONCLUSIONS

Despite best efforts, hundreds of thousands of students are not succeeding in postsecondary general education mathematics courses each year. This situation is of particular concern, because failure to pass a required general education mathematics course may jeopardizes one's ability to complete an undergraduate degree. In addition, this issue takes on an added dimension of urgency as the US struggles to improve both the overall percentage of citizens who attain a postsecondary degree as well as to close the educational attainment gap between minority and non-minority populations. As reported by the National Center for Education Statistics (2002), the percentage of African-American students taking remedial courses when entering college is 19.5%, with Hispanics at 20.4%, Asian/Pacific Islanders at 12.6%, and Whites at 13%. Colleges and universities across the nation thus need to find a way to remedy this situation that is scalable, cost effective, easy for faculty to embrace, and appealing to students.

The MMM was developed and implemented at UM with these factors in mind. The success rates at UM mirror those found in the literature and, our findings are consistent with the literature regarding comparative performance differences between black and white students in traditional courses. Black students are found to perform significantly lower than white students in both the DSPM and regular classes when taught traditionally.

Our results suggest that the MMM was positive and significant for raising success rates in Elementary Calculus. In addition, the results show the MMM is a potential vehicle for closing the achievement gap between black and white students. Overall, our data suggest that MMM increases success and decreases dropout rates for these general education mathematics courses. The positive results may be attributed to the structure and interactive nature of the MMM which forces a daily involvement on the part of the student. Students in the MMM are engaged in class and at home in a non-threating manner. This type of active engagement along with the use of technology is in-line with reform pedagogy.

From a practical standpoint, postsecondary institutions need to find a cost effective, scalable, and impactful method to address low success rates in general education mathematics courses. After an initial start-up cost in establishing suitable computer labs, the MMM distributes department resources in a cost effective way. First, the MMM can employ undergraduate student assistants, rather than graduate students, second, because grading is automated in MyMathLab, this eliminates the need to have graders for these classes. This frees up advanced graduate students to be employed as instructors instead of graders.

Although the results of this study cannot be interpreted as causal due to the lack of student random assignment to teaching methodology, the results do present some large-scale evidence that the MMM model may improve student success in Elementary Calculus, may lower dropout rates in College Algebra, and lower overall costs. Future work is needed to perform a rigorous, comparative evaluation of the model is in order to provide concrete causal statistical evidence of its validity and in turn offer concrete motivation for scale-up. Also, to further understand the reasons *why* the MMM is effective in improving student success and retention, it is important to collect qualitative data to complement this quantitative analysis. Another extremely interesting comparison would be to compare the NCAT Emporium model with fixed-attendance as exemplified in the MMM to the NCAT Emporium model with flexible attendance (students are not required to log a certain number of hours per semester on the software). Such a comparison would address whether the more structured nature of the MMM benefits students.

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