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INTERVENTION, EVALUATION, AND POLICY STUDIES

A Randomized Controlled Trial of a Modularized, Computer-Assisted, Self-Paced Approach to Developmental Math

Michael J. Weiss[a] and Camielle Headlam[a]

ABSTRACT

Community colleges are a large sector of postsecondary education. In 2016–2017, the United States had nearly 1,000 public 2-year postsecondary institutions (community colleges), serving almost nine million students, representing 39% of all undergraduates. The majority of entering community college students require developmental (or remedial) math. Success rates in the developmental math course sequence and college more broadly are discouragingly low. Policymakers, practitioners, and researchers alike are eagerly searching for reforms to improve success rates, but there is a dearth of causal evidence on the effectiveness of most proposed reforms. We sought to answer the following question: what effect does a modularized, computer-assisted, self-paced approach to developmental math (compared with a more "traditional" direct-instruction course alternative) have on students' likelihood of completing the developmental math course sequence? Findings from a randomized controlled trial (n =1,403) are presented. The program was well implemented; however, we did not find evidence that this approach was superior to the "traditional" math class. Although these results are disappointing, they are important because modularization and self-paced computer-assisted instruction are popular reforms.

KEYWORDS
community college
randomized controlled trial
developmental math
modularized
computer-assisted
instruction

Introduction

In the United States, community colleges play a vital role in advancing the nation's agenda to increase college degree attainment and technical skills training, as they serve a significant proportion of postsecondary education students. In 2016–2017, nine million students attended public 2-year colleges (community colleges), representing 39% of all undergraduates. The open admissions and relatively low cost of community colleges (compared with 4-year colleges and universities) have contributed to unprecedented access to postsecondary education. However, rates of successful degree completion leave much room for improvement. Nationwide, among first-time, full-time community college students in the 2013 cohort, only 25% graduated within 3 years (Ginder, Kelly-Reid, & Mann, 2017).

One of the greatest challenges facing community colleges is that most entering students (approximately 59%) are deemed academically underprepared for college-level math and are referred to developmental math courses (Chen, 2016). These courses are

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intended to prepare students for college-level work; however, most students who place into remedial math courses never complete them, move on to introductory college-level math courses, or earn a degree (Attewell, Lavin, Domina, & Levey, 2006; Bailey, Jenkins, & Leinbach, 2005; Bailey, Jeong, & Cho, 2010).

While the low success rates of students who are referred to developmental education are well documented (Bailey et al., 2010), there is a dearth of causal evidence on the effectiveness of strategies to improve outcomes for these students. In fact, the U.S. Department of Education's What Works Clearinghouse (WWC) recently published a practice guide of strategies to help postsecondary students in developmental education and after reviewing 25,697 studies, only 10 met the WWC evidence standards with or without reservations. Moreover, of the six practices recommended in the guide, only three had *any* evaluations meeting the WWC evidence standards supporting them, indicating that causal evidence on strategies to improve developmental education is desperately needed by postsecondary administrators and policy makers (Bailey et al., 2016).

The present study contributes to this literature via a rigorous evaluation of a widespread type of developmental education reform—the division of remedial math courses into discrete, single-unit modules, in which the content is delivered via self-paced, computer-assisted instruction. The popularity of this type of reform extends from statewide policies to independent creation of homegrown programs at individual colleges. A 2016 survey of a nationally representative sample of 911 2- and 4-year colleges in the United States found that 40% of institutions offered self-paced approaches to developmental math education and 32% of colleges used computer-based learning to support underprepared students (Zachry Rutschow & Mayer, 2018, personal communication). In the past few years, policy makers in Virginia and North Carolina independently standardized the developmental education curricula across all the colleges in their respective states and modularized their developmental math courses (Kalamkarian, Raufman, & Edgecombe, 2015).

At Tarrant County College (TCC) in Texas, math department faculty created ModMath, a modularized, computer-assisted, self-paced developmental math course sequence, which is the subject of the present study. In this article, we present findings from a 1,400-person randomized controlled trial of ModMath. The sections that follow provide context for the study, describe the program model and theory of change, and detail the study design and results. We conclude with a discussion on the implications of the findings.

Background and Study Context

Developmental Math at TCC

When the present study began, the developmental math sequence at TCC consisted of two courses: Developmental Math 1 and Intermediate Algebra. Students were referred to one of the two developmental math classes or into college-level math using the Texas Success Initiative (TSI) Assessment.[1] The courses, which all followed the same

[1]Students may be exempt from taking the TSI Assessment if they obtain a certain score on their SAT, ACT, or Texas statewide high school test; have successfully completed a college-level math course; or are active or veteran members of the military.

Table 1. Features of developmental math course offerings at Tarrant County College.

Course type	Sequence structure	Instructional delivery
ModMath	• Six 5-week modules • Each mod is 1 credit	• Computer-assisted instruction • Self-paced • Support from instructor and aide • Acceleration possible
Lecture-based	• Two 16-week courses • Each course is 3 credits	• Instructor-led lectures • Instructor sets pace
Computer-assisted lecture	• Two 16-week courses • Each course is 3 credits	• Instructor-led lectures and computer assisted instruction (varies by instructor) • Instructor sets pace
Emporium	• Two 16-week courses • Each course is 3 credits	• Computer-assisted instruction • Self-paced • Acceleration possible

curriculum, were offered in a variety of course formats, including lecture-based courses, computer-assisted lectures, Emporium (described later), and ModMath.

The focus of this article is the effectiveness of TCC's ModMath program. However, as Holland (1986) noted, "The effect of a cause is always relative to another cause" (p. 946). In other words, there is no singular effect of TCC's ModMath program—it depends what it is being compared with. In the present study, we examine the effectiveness of TCC's ModMath relative to the alternative developmental math course offerings at TCC. Table 1 provides a brief overview of ModMath and these alternative offerings, which is essential for understanding the service contrast and thus the estimated effects on academic outcomes. While the control group's experiences reflect some participation in all three alternatives, most control group students enrolled in lecture-based courses. In the Program Implementation section, we provide greater detail on participation in these alternative offerings and students' experiences in these courses.

ModMath Model, Theory of Change, and Prior Research

Program Model

ModMath is a developmental math reform that changes the structure of the developmental math sequence and the instructional delivery of the curriculum, but not the course content itself. ModMath's course structure and instruction encompass four key components: (1) modularized courses, (2) computer-assisted instruction, (3) a diagnostic assessment, and (4) on-demand, personalized assistance. Figure 1 depicts the ModMath theory of change or logic model. The first two columns describe each component of the program and associated practices. The last two columns list intended student outcomes, and the middle column explains the mechanisms through which each set of practices was hypothesized to improve outcomes for ModMath students.

Modular Courses: The core component of ModMath is a structural change that divides each of the two semester-long developmental math courses into three 5-week one-credit modules or "mods" (mods 1–6). All six modules are offered in any given ModMath course section. Students typically enroll in three modules—the equivalent of one traditional developmental math course—each semester.

<table>
<tr><th>Component</th><th>Key Practices and Features</th><th>Mechanisms</th><th colspan="2">Student Outcomes</th></tr>
<tr><td>Diagnostic Assessment (MyMathTest)</td><td>○ Fine-tuned for module placement
○ Aligned with course content</td><td>○ Accurate placement resulting in close alignment of content with students' prior math knowledge</td><td>Short-Term Academic Progress</td><td>Long-Term Academic Progress</td></tr>
<tr><td>Modularized Courses</td><td>○ Each semester-long course divided into three 5-week modules
○ Each module worth 1 developmental math credit
○ Modules align with the standard curriculum</td><td>○ Students earn one credit for each mod passed, resulting in sense of progress
○ Students who fail or stop attending a mod can repeat in the next 5-week session rather than wait until next semester to repeat whole course, resulting in increased persistence</td><td rowspan="3">○ Enrollment
○ Proportion of the developmental math sequence completed
○ College-level math course completion
○ Credits earned in subjects other than math</td><td rowspan="3">○ College-level credits earned
○ Total credits earned
○ Persistence
○ Degree/ certificate attainment
○ Transfer rates to 4-year colleges</td></tr>
<tr><td>Computer-Based Instruction (MyMathLab)</td><td>○ 100 percent of class time in computer lab
○ Various content delivery methods for instruction (video, presentation, textbook)
○ Mastery learning
○ Extra support available via software</td><td>○ Allows for self-paced learning
○ Allows for completing up to 6 modules in a single semester
○ Students move on only after demonstrating mastery of material
○ Variety of content delivery methods and frequent assessments facilitates mastery</td></tr>
<tr><td>Personalized, On-Demand Assistance</td><td>○ Each class staffed with an instructor and aide
○ Instructor and aide circulate during class, providing one-on-one assistance</td><td>○ Increases the amount of one-on-one instructor-student interactions, allowing more academic and emotional support</td></tr>
</table>

Figure 1. A logic model for ModMath: Components, practices, mechanisms, and outcomes.

Computer-Assisted Instruction: ModMath's course content is delivered via Pearson's instructional software program called MyMathLab. Students meet in computer classrooms at regularly scheduled times and work independently through the course material using instructional videos, PowerPoint slides, or an online or hard copy version of the textbook. Because instruction is self-paced, students may accelerate and complete more than three modules in each semester.

Diagnostic Assessment: To place students into one of the six computer-assisted modules, ModMath supplements the college's standard math placement test—the TSI Assessment—with an additional placement exam, Pearson's MyMathTest.[2] MyMathTest is intended to be more fine-tuned than TCC's standard placement exam, identifying which module matches students' demonstrated math knowledge and skill deficits. Students are referred to a specific module depending on their skill needs as determined by MyMathTest results and must complete the remaining set of modules in order to complete developmental math.

On-Demand, Personalized Assistance: ModMath is designed so instructors serve as facilitators who provide individualized support to students, as opposed to whole-group instruction. Each class, which typically enrolls 24 students, is staffed with an instructor and an instructional aide. Compared with traditional lecture-based courses, the highly personalized structure of ModMath provides more opportunity for instructional staff to provide one-on-one academic and emotional support to students.

Theory of Change

ModMath is theorized to improve student outcomes by addressing common challenges to developmental math instruction. A major pedagogical challenge in developmental

[2]The exam, which is developed using Pearson's MyMathTest platform, allows faculty to create a customized placement exam by selecting questions from the software's test bank of problems that align with TCC's developmental math curriculum.

math is that the courses typically serve heterogenous students with a wide range of academic abilities, learning styles, and personal needs. Unless an instructor can accommodate these differences through differentiated instruction and other methods, such as supplemental academic support, students may fall behind, disengage, or fail (Tomlinson & Kalbfleisch, 1998). Several ModMath components allow for greater differentiation than is typically feasible in traditional lecture-based classrooms.

First, the modular structure, coupled with the fine-tuned diagnostic exam, is intended to allow for more precise placement than the standard assessment. This should allow students to enter a modular sequence at a level that is closely aligned with their prior knowledge, so they focus only on topics in which they need remediation (Bickerstaff, Fay, & Trimble, 2016; Bracco, Austin, Bugler, & Finkelstein, 2015). Second, ModMath tailors instruction to each student by combining computer-based learning via the instructional software package with on-demand, personalized assistance from the instructor and aide. This "hybrid" learning environment has been linked to improved student outcomes (Chekour, 2017; Means, Toyama, Murphy, Bakia, & Jones, 2009); although the evidence is mixed (Xu & Jaggars, 2011). Instructional software is thought to accommodate students with various learning styles and abilities by providing diverse instructional materials and allowing for self-paced instruction. Both features are intended to increase student engagement and performance (Goldschmid & Goldschmid, 1973; Subban, 2006). Furthermore, self-paced instruction should allow some students to accelerate and complete more than the standard three modules per semester.

In general, instructional software, such as MyMathLab, is theorized to facilitate optimal learning by placing students in Vygotsky's (1980) zone of proximal development—the developmental level where instructional content is just beyond students' current knowledge—a level where students are capable of learning new material with assistance from a more knowledgeable tutor. In ModMath, this tutoring can come from the software, which includes several help features to guide students through new math problems, or from the instructor, who can fill in conceptual gaps or provide alternative methods of problem solving to those provided by the software. Computer-assisted instruction is also theorized to facilitate mastery learning because it allows students to take frequent assessments, receive formative feedback on their learning, and progress only when they have mastered the material. This process is thought to improve student performance in developmental and in more advanced math courses (Bishop, 2010; Epper & Baker, 2009; Twigg, 2005).

Another common challenge to developmental math instruction is that many students have a history of underperformance in math, suffer from math anxiety, or lack confidence in their mathematical abilities (Dwinell & Higbee, 1989; Taylor, 2006). By staffing each course with an instructor and aide who provide individualized assistance, ModMath increases instructor–student interactions and allows opportunities for instructional staff to provide not only academic but also emotional support to students. This support may build student confidence and improve academic progress in math, as greater connections to staff can increase student feelings of belonging and facilitate persistence (Tinto, 1999).

Finally, another challenge to developmental math instruction, especially in community colleges, is that many students stop attending classes or drop out of college. In traditional courses, students who drop out mid-semester do not receive any credit for already completed work and must restart the course from the beginning. The modularized structure allows students to leave and return, without losing as much ground. Furthermore, students using ModMath earn credits incrementally, which may facilitate a sense of accomplishment as they experience "small wins" (Weick, 1984) toward the goal of completing the entire developmental math sequence.

Effectiveness of Modularized, Computer-Assisted Developmental Math Programs

There is limited rigorous evidence on the efficacy of modularized, computer-assisted developmental math courses, like ModMath, and findings from existing non-experimental studies are mixed. For example, Squires, Faulkner, and Hite (2009) compare developmental (and college-level) course completion rates pre- and post-computer-assisted modularization and find increases in pass rates. On the other hand, Kalamkarian et al. (2015) studied North Carolina's and Virginia's modularized developmental math programs and, based largely on descriptive outcome data, concluded that pacing and attrition were major issues in self-paced, computer-assisted modules, as a significant portion of students did not complete the expected number of modules for the given semester. In another study, Ariovich and Walker (2014) compared the pass rates of students in modularized classes to pass rates of students in traditional courses (without controlling for any student background characteristics). They found that students who opted to take modularized, computer-assisted developmental math performed worse than students who opted to take traditional developmental math.

The mixed results of modularized, computer-assisted, self-paced developmental math courses may relate to variations due to program implementation and institutional context. Fay (2017) concluded that high school students in Tennessee experienced higher pass rates than community college students using the same computer-assisted modularized developmental math program because the high schools had more structured classroom environments, such as rigorous attendance policies and frequent class meetings, than the community colleges, which were characterized by more flexibility and student autonomy. Bickerstaff et al. (2016) found that stand-alone modules (in which all students are in the same module) allow for instructional flexibility (as they can be taught via lecture or instructional software) but create additional exit points at which students may fail to reenroll in the next module. On the other hand, computer-assisted courses that offer several modules in one course section reduce the number of exit points but may slow student progression.

At least one quasi-experimental study has been conducted. Following a statewide redesign of remedial education in Tennessee, some community colleges divided their developmental math sequence into computer-assisted modules. Boatman (2012) evaluated two programs of this type and found similarly mixed results: The computer-assisted modularized courses resulted in positive effects at one institution, but no effects at the other community college.[3]

[3]This study uses a complicated design that combines regression discontinuity, instrumental variables, and difference-in-differences.

The inconclusive literature on modularized, computer-assisted courses highlights the need for randomized field trials to test the efficacy of the approach. The present study aims to begin to fill this gap.

Evaluation

The Study College: TCC, Texas

The study took place at the TCC District. With six campuses and an annual enrollment of about 50,000 students, TCC is one of the largest community college systems in Texas. This study took place at the Northeast Campus, located in Hurst, a suburb between Fort Worth and Dallas, Texas. The campus offers a range of associate degree programs that prepare students to enter professional careers or transfer to 4-year institutions.

Research Questions

The primary goal of the evaluation is to answer the following question:

- What effect does the opportunity to enroll in ModMath (compared with the opportunity to enroll in the college's "traditional" math courses) have on students' likelihood of *completing the developmental math course sequence*?[4]

We were also interested in any positive spillover effects or negative side effects on progress outside of math, which may be caused by ModMath.

In addition to this overarching goal, we sought to understand several questions related to the implementation of ModMath and the "traditional" math courses with which ModMath is compared. They include the following:

- To what degree were ModMath services and activities implemented as planned (i.e., to what degree is their fidelity to the program model)?
- To what degree were the services experienced by program group students different from those experienced by control group students (i.e., to what degree was there a contrast between the program and control conditions)?

Research Design

We used a random assignment research design to estimate the effect of the ModMath program compared with a "business-as-usual" control condition at the college, generally a more traditional, lecture-based course. Included in the evaluation were eligible students (those in need of developmental mathematics, based on placement test scores)

[4]This question and the implied primary outcome of interest were specified in an internal (i.e., not published) analysis plan written prior to conducting analyses. The main outcome (confirmatory) of interest was having successfully completed the developmental math course sequence (for more on what is meant by "confirmatory," please see Schochet, 2008).

Table 2. Analytic sample of students by cohort and experimental group.

Cohort	Program group ($n = 826$)	Control group ($n = 577$)
Spring 2014	86	79
Fall 2014	285	201
Spring 2015	133	85
Fall 2015	322	212

Note. $N = 1{,}403$. Calculations made using MDRC's random assignment system.

who (a) were willing to participate in the ModMath program, (b) filled out a baseline survey, and (c) signed an informed consent.[5] After completing the baseline survey and informed consent, students were randomly assigned, through a computer algorithm controlled by the research team, to either the program or control group. Program group members had the opportunity to participate in ModMath. Control group members had the opportunity to participate in any of the college's other developmental math course offerings and any support services, just not ModMath. Four cohorts of students were randomly assigned, one prior to the spring and fall semesters in 2014 and 2015. In total, 1,408 students were randomly assigned (828 to the program group, 580 to the control group). Five students are not included in any analyses (two in the program group, three in the control group) because they withdrew from the study or their consent form was not recovered, leaving an analytical sample of 1,403 students.[6] Table 2 provides the size of the analytic sample by cohort and experimental group. Most students (73%) entered the study in the two fall semesters. Overall, 59% of the sample was assigned to the program group. The proportion was smaller for the Spring 2014 cohort because the original research design involved a 1:1 random assignment ratio. This was modified to a 3:2 ratio for the three later cohorts to increase the number of students interested in ModMath who were offered the program.

Student Characteristics and Baseline Balance Tests

Upon joining the study, students completed a baseline survey covering information about their demographic characteristics, family and educational backgrounds, and experiences with math. These data are used to describe the sample and compare the pretreatment measured characteristics of program and control group sample members. Overall the sample is diverse and demographically similar to community college students nationally, and the program and control groups were very similar at the outset of the study.

Table 3 shows that, as is the case in the undergraduate population nationally, most students in the study sample are female. The analytic sample is racially diverse: 46% White, 29% Hispanic, and 19% Black. This is similar to the racial demographics at public institutions nationally, which are 50% White, 25% Hispanic, and 14% Black (Snyder, de Brey, & Dillow, 2018). At the start of the study, 60% of students were younger than 25 years old; 22% were between 25 and 34 years old; and about 18% were older than

[5]For more details on the recruitment process, see Gardenhire, Diamond, Headlam, and Weiss (2016).

[6]The overall attrition rate is 0.36% and the rate of differential attrition (the difference between program group attrition and control group attrition) is 0.28 percentage points.

Table 3. Characteristics of students in the study.

Outcome (%)	Program group ($n = 823$)	Control group ($n = 575$)	Difference	Standard error
Female	63.5	65.0	−1.5	2.6
Age				
18 and younger	22.1	21.6	0.5	2.2
19–24	38.2	38.8	−0.6	2.6
25–34	22.0	21.4	0.6	2.2
35–44	10.0	11.1	−1.2	1.7
45 and older	7.8	7.1	0.6	1.4
Race/ethnicity[a]				
Hispanic	28.7	27.3	1.4	2.5
White	46.2	45.4	0.7	2.8
Black	19.2	20.1	−0.9	2.2
Other	5.9	7.2	−1.3	1.4
Completed 12th grade	86.8	88.1	−1.3	1.8
First person in family to attend college	32.9	34.8	−1.9	2.6
Planned enrollment this semester				
Less than part time (fewer than 6 credits)	17.2	18.5	−1.3	2.1
Part time (6–12 credits)	39.0	38.9	0.1	2.7
Full time (12 credits or more)	43.8	42.6	1.2	2.7
Planning to work this semester				
No	19.2	18.8	0.4	2.1
Yes, part time (less than 30 hours a week)	29.9	32.3	−2.5	2.5
Yes, full time (30 hours a week or more)	44.3	42.4	1.9	2.7
Missing	6.6	6.4	0.1	1.3
Failed a math class in the past	52.9	54.3	−1.4	2.7
Missing	6.3	7.3	−1.0	1.4
TSI math placement				
College-ready or exempt[b]	7.2	6.3	0.9	1.4
Placed one level below college-ready	9.2	8.7	0.5	1.6
Placed more than one level below college-ready	50.5	54.1	−3.5	2.7
Math placement information is unknown or missing[c]	33.0	31.0	2.1	2.5

Note. $N = 1{,}398$. Rounding may cause slight discrepancies in sums and differences. *Missing* shows the percentage of survey respondents who did not answer the question. Missing values are reported only for items with more than 5% missing. Calculations were made using data from the baseline survey of Tarrant County College (TCC) students and TCC placement test data. Five students never filled out baseline information surveys and are excluded from this table.
TSI = Texas Success Initiative.
[a]Respondents who said they were Hispanic and chose a race are included only in the Hispanic category. Respondents who said they were not Hispanic and chose more than one race are included in the Other category. The Other category also includes respondents who chose Asian, American Indian, or Pacific Islander.
[b]Includes students who were found to be ready for college, who received waivers from testing requirements, who were exempt from testing requirements, or who had previously completed testing requirements.
[c]Includes students who were not included in the TCC placement test data.
***p = .01; **p = .05; *p = .10.

35 years old. This age breakdown mirrors national statistics among part-time students, whereas full-time students tend to be younger (NCES, 2018a). Many students in the study had characteristics associated with a low likelihood of academic success (Engle, 2007). For instance, a third of the students in the study are the first in their families to attend college.[7] Around 43% of the analytic sample reported that they planned to enroll in school full-time during the first study semester.[8] Nearly three-quarters of sample members said that they planned to work during the upcoming semester, and about 44% planned to work full time.[9] In addition, more than half of students reported that they

[7]Nationally, 24% of college students are first-generation college students (Redford & Hoyer, 2017).
[8]Similarly, 37% of students at 2-year public institutions enrolled full time in 2015 (NCES, 2018a).
[9]Similarly, at 2-year institutions nationally, 45% of part-time undergraduate students worked 35 hours or more per week in 2015; 46% of full-time and 76% of part-time students held employment (NCES, 2018b).

had failed a math class in the past. Also shown in Table 3, the pretreatment characteristics of program and control group students are very similar.[10]

Instructor Characteristics

ModMath instructors were selected in one of two ways: Full-time instructors could volunteer to teach ModMath, while adjunct instructors were assigned to teach ModMath by the math department chairs. Developmental math instructors were surveyed about their demographic characteristics, educational and professional backgrounds, and teaching experiences to gauge whether the instructors teaching ModMath might differ from other instructors, particularly in ways that could affect students' academic outcomes. For example, if ModMath classes were taught by more experienced instructors, and if instructor experience is associated with effectiveness, then program group students might be more likely than control group students to pass developmental math not because the ModMath program itself is more effective, but because its instructors had more experience (see Weiss, 2010 for details on the implications of instructor selection in individually randomized trials).

Table 4 shows that the two groups of instructors were similar in many regards. Most instructors in both groups were White, with an average age of around 48 or 49. Instructors in both groups reported having taught for an average of 17 years and having taught developmental math specifically for 10 years. Both groups were also roughly equally likely to have received different types of professional development within the past 2 years.

In other ways, however, the groups were different. For example, ModMath instructors were more likely to be female (64%) than other instructors (53%). ModMath instructors were also somewhat more involved in the math department than other instructors: They were more likely to have served as math department administrators (17% vs. 11% of other instructors) or to have served on a committee on math curriculum, evaluation, or assessment (32% vs. 26%). These differences should be kept in mind when considering the findings.

Data Sources

Data for this mixed methods evaluation came from qualitative and quantitative sources. These data sources are briefly described below; for more details, see Gardenhire, Diamond, Headlam, and Weiss (2016).

Qualitative data were collected from focus groups with five groups of students (ranging in size from 4 to 20 participants), one group of ModMath instructors and one group of traditional developmental math instructors (17 participants total), and one group of academic advisers (seven advisers). Interviews with 12 TCC staff members involved in the ModMath program were conducted. Focus groups and interviews covered typical student and instructor assessment and instructional activities; reflection on course structure, pacing, and difficulty; student progression through each course type; and

[10]See Appendix A.1 in Gardenhire et al. (2016) for a comprehensive list of data reported by students on the baseline survey, as well as a comparison of program and control group students on these measured characteristics.

Table 4. Characteristics of developmental math instructors.

Response	Sample size	ModMath instructors	Other instructors	Difference	Standard error
Male (%)	41	36	47	−11	15.7
Age (years)	28	48	49	0	6.6
Missing (%)	42	22	47	−26*	14.4
Race/ethnicity[a] (%)					
Hispanic	42	0	5	−5	4.8
White	42	83	74	9	13.0
Asian	42	0	5	−5	4.8
Black	42	4	5	−1	6.8
American/Indian	42	4	0	4	4.8
Missing	42	9	11	−2	9.3
Years of teaching experience					
Developmental math	41	10	10	0	3.5
All subjects	42	17	17	−1	4.0
Adjunct or full faculty member (%)					
Adjunct	42	61	68	−8	15.2
Full faculty member	42	35	32	3	15.0
Other	42	4	0	4	4.8
Highest degree earned (%)					
Bachelor's	42	9	11	−2	9.3
Master's	42	83	79	4	12.5
Doctorate	42	9	11	−2	9.3
Current or former math department administrator (%)	42	17	11	7	11.1
For degrees earned, majors or concentrations[b] (%)					
Mathematics/statistics/economics	42	87	84	3	11.1
Education (focused on math education)	42	35	42	−7	15.4
Education (other focus)	42	17	5	12	10.1
Engineering/computer science/science	42	48	32	16	15.4
Other	42	17	5	12	10.1
Participated in a committee for math curriculum, evaluation, or assessment (%)	41	32	26	6	14.6
Participated in a campus-level committee (%)	42	26	32	−5	14.3
Within the past 2 years, received professional development in[b] (%)					
Math content knowledge	41	68	63	5	15.2
Computer-assisted instruction	41	59	47	12	15.9
Teaching methods/pedagogy	39	81	78	3	13.3
Average instructor agreement regarding students (1 = very true, 4 = not very true)					
They can understand the material	42	1.5	1.6	−0.1	0.2
They will succeed in college algebra	40	2.0	2.2	−0.1	0.2
They don't study enough	42	1.8	1.7	0.1	0.2

Note. Total survey respondents $N = 42$. ModMath respondents $N = 23$. Other respondents $N = 19$. Rounding may cause slight discrepancies in sums and differences. "Missing" shows the percentage of survey respondents who did not answer the question. Missing values are only reported for items with more than 5% missing. Calculations made using data from survey of Tarrant County College developmental math instructors.

[a]Respondents who said they are Hispanic and chose a race are included only in the Hispanic category.

[b]Distributions may not sum to 100% because categories are not mutually exclusive.

$^{***}p = .01$; $^{**}p = .05$; $^{*}p = .10$.

discussion on institutional and course-specific developmental math education policies. Finally, the research team informally observed ModMath classrooms 10 times and control group classrooms 5 times. Observers recorded data on the classroom environment, student and staff activities throughout the class period, and student engagement during the instructional period. The qualitative data were used primarily to understand the program implementation and similarities and differences in the experiences of program and control group members.

Quantitative data include a baseline survey taken just prior to random assignment; TSI placement test records, which were used to determine developmental math course placement for most control group students; MyMathTest placement scores, which were used to determine module level for most program group students; student transcript records, which we use to measure academic outcomes; a student survey conducted during program and control group students' first semester after random assignment, covering topics such as student engagement in their math courses, typical in-class activities by the student and instructor, and assessment of the difficulty and pacing of their math courses; and an instructor survey given to all math instructors who taught at least one developmental math class between Spring 2014 and Fall 2015. The student survey had an overall response rate of 72% (1,012/1,403). Program group members' response rate was 75% (620/826) and control group members response rate was 68% (392/577). The instructor survey had an overall response rate of 82% (42/51).[11]

Fidelity of Implementation

Fidelity to the ModMath model was assessed based on adherence to the four core components of the program model—modular courses, diagnostic assessment, computer-assisted instruction, and on-demand, personalized assistance. These components were identified from prior research on the program and from explicit discussions with the ModMath program designers about the program model and theory of change. For each core component, strong fidelity was determined to be the availability of the core component for most students, while weak fidelity was determined to be the absence of the core component for most students. Process mechanisms or the extent to which the program components and practices led to a modification in behaviors for most students were also examined.

Course transcript data were used to assess whether ModMath courses were offered as discrete one-credit modules and whether most program participants took ModMath. Transcript data were also used to understand how students progressed through the modules and earned credits. Interviews and focus groups with staff and students contributed to understanding how the modular structure impacted student behavior and sense of achievement. Staff interviews and course documents were used to assess curriculum alignment—or the extent to which ModMath covered the same content as the lecture-based courses, as planned. Placement test data were used to examine adherence to the fine-tuned assessment requirement, measured by the proportion of students who took the exam prior to their first ModMath course, as prescribed by the program model. As a process measure, students' placement using the fine-tuned exam was compared to their placement with the standard exam to determine whether the ModMath diagnostic altered placement for most students.

For computer-assisted instruction and on-demand personalized assistance, classroom observation data were used to understand the classroom practice, and survey data were used to assess whether most students spent the majority of their math class time working independently on the computer software with assistance from the instructor as requested or needed. As process measures, student focus group and course transcript data were used

[11]It is difficult to determine response rates for ModMath instructors and other instructors because some instructors taught both types of classes, and we are not certain what types of classes nonrespondents taught.

to measure student pacing and acceleration, and focus group data were used to understand how on-demand, personalized assistance impacted student engagement and support.

Qualitative data were collected at two points—once in each of the first two semesters following random assignment. Following each field visit, transcripts of interviews and focus groups were coded using preset codes and emerging themes.[12] Data from the various sources were triangulated to determine whether each component, and subsequently the overall program, was implemented with weak or strong fidelity to the model.

Academic Outcomes

The primary academic outcome of interest was completion of the developmental math sequence. To provide context when interpreting ModMath's effect on completing developmental math, several additional academic outcomes are examined. These outcomes are described below. All academic outcomes were derived from the college's administrative records, including transcript records, TSI placement test records, and MyMathTest placement scores. All 1,403 students in the analytic sample are included in analyses that examine the academic outcomes. Students without transcript records are considered not to have enrolled or to have made any further progress in math. All outcomes were measured at the end of the first, second, and third semester after random assignment.

Enrollment*:* Two indicators of enrollment are considered:

- *Enrolled in college*. Enrollment is defined as of the add-drop deadline.
- *Enrolled in any math class*. Enrollment in any math class is defined based on enrollment in a module *or* a math course.

Enrollment outcomes are important to consider for at least two reasons. First, it is possible that ModMath could increase persistence in college. This could occur if students find the approach more engaging than the traditional approach or if ModMath students perform better in math and consequently have a more positive school experience. Second, our main math-focused outcomes are affected by enrollment (when students are no longer enrolled, they no longer make any progress in math), so enrollment rates provide important context when interpreting the math-focused outcomes. In terms of outcome levels, due to dropout alone we expect marginal increases in math progress to decline over time as larger proportions of students are not attempting any classes. This is also true with respect to impacts, where any program effects on enrollment have the potential to carryover to math progress.

Developmental Math Progress/Completion*:* Several measures of developmental math progress and/or completion are examined:

- *Average percentage of developmental math sequence completed*. One indicator of progress is the percentage of the developmental course sequence

[12]A codebook with preset codes was developed prior to field visits to classify data related to each core program component. Following each field visit, transcripts of interviews and focus groups were obtained using a professional transcription firm. These transcripts were uploaded to Dedoose, a software program for qualitative data analysis.

completed.[13] Because students in ModMath can achieve smaller increments of success than students in traditional courses, this measure may favor the program group.

- *Earned at least one developmental math credit*. Another indicator that a student made *any* progress is whether he or she passed at least one module (one credit) or one course (three credits) since random assignment. Since students in ModMath can complete a one-credit module and students in traditional courses must complete an all-or-nothing three-credit course, this measure of progress favors the program group.
- *Completed first half of developmental* sequence. A final indicator of progress is whether students surpass the halfway milestone in the developmental sequence—Mod 3 or Math 0361 (the lower-level developmental math course). This may be the fairest *progress* milestone comparison since ModMath and the traditional course sequence have a similarly defined halfway point.
- *Completed developmental sequence (college-ready)*. The primary outcome of interest is completion of the developmental math sequence, which is defined as having passed Mod 6 or developmental Math 0362 since random assignment. Students achieving this milestone are considered "college-ready" in math and may proceed to college-level course work.

Estimation

To obtain a regression-adjusted estimate of the causal effect of the opportunity to participate in ModMath, we use the following general linear model:

$$Y = \gamma \boldsymbol{RB} + \beta T + \varepsilon \quad (1)$$

where Y is the outcome of interest; $\boldsymbol{RB}$ is a vector of four random assignment block indicators (one for each unique cohort in the study); T is a treatment assignment indicator, set equal to one if a student is assigned to treatment and zero otherwise; and ε is a random error term. Standard errors are Huber-White heteroskedastic robust standard errors.[14] Estimated effects presented in the tables are the $\hat{\beta}$s for the relevant outcome. For simplicity, the main analyses presented in this article do not include any pretreatment control

[13]For example, a program group student who completes Mod 1 but not Mod 2 is one-sixth of the way through the developmental sequence, or about 17%. A student completing Mod 2 but not Mod 3 has completed two-sixths of the sequence, or about 33%. For control group students, a student completing the developmental course Math 0361 (lower level math) has completed half of the sequence, or 50%, while a student completing developmental course Math 0362 has completed the sequence.

[14]Clusters of students were in the same class together; however, we do not use cluster-robust standard errors as some researchers might. In this study, students were the unit of random assignment. As described by Abadie, Athey, Imbens, and Wooldridge (2017), "clustering is in essence a design problem, either a sampling design or an experimental design issue." We did not sample clusters of students, and assignment to treatment was not clustered; thus, there is not support for making cluster adjustments due to sampling design or experimental design.

In the absence of sampling clusters of students or cluster random assignment, cluster adjustment can still be justified if the estimand assumes the clusters in the study are like a random sample from a super population. Our target of inference is the effect of the opportunity to participate in ModMath for the students, classes, and instructors in the study, again implying no need for cluster adjustment. In addition, note that cluster robust standard errors tend to be larger than non-cluster robust standard errors. Since our primary findings are not statistically significant, using cluster robust standard errors should not change the statistical significance or substantive conclusions of this article. Finally, due to data limitations we cannot confidently determine which students were in which sections.

Table 5. First program semester math course type enrollment.

Outcome (%)	Program group ($n = 826$)	Control group ($n = 577$)	Estimated effect	Standard error
First semester				
ModMath	83.1	0.2	82.9***	1.3
Lecture-based	2.1	56.9	−54.8***	2.1
Non-modularized computer-assisted	0.5	20.4	−19.9***	1.7
Other[a]	1.1	3.0	−1.9**	0.8
No math course	13.3	19.6	−6.3***	2.0

Note. $N = 1{,}403$. Estimates are adjusted by cohort. Rounding may cause slight discrepancies in sums and differences. Calculations made using transcript data from Tarrant County College.
[a]Includes math courses where the section type is unknown.
***$p = .01$; **$p = .05$; *$p = .10$.

variables. As a sensitivity check for the main outcomes of interest we re-ran the analyses including a set of covariates that could plausibly be related to outcomes. These analyses do not yield substantively different results than those presented.

All analyses of academic outcomes are intent-to-treat and include all 1,403 students regardless of compliance with their experimental group. As discussed in more detail in the program implementation section below (see Table 5), 83.1% of the program group and less than 1% of the control group participated in at least some part of ModMath during the first semester after random assignment. Around 80% of the control group and less than 4% of the program group enrolled in another type of math course during that semester. The remaining students did not enroll in any math courses in the first semester after being randomly assigned.

The probability of being assigned to the treatment group varied across random assignment blocks. To account for the varying treatment assignment probabilities, inverse probability of treatment weights are used to ensure an unbiased impact estimator.[15] Weights were created as follows:

$$w_{ij} = T_{ij}\left(\frac{T_{..}}{T_{.j}}\right) + (1-T_{ij})\left(\frac{1-T_{..}}{1-T_{.j}}\right), \tag{2}$$

where:

- $T_{ij} = 1$ if individual i in random assignment block j was assigned to the program group and 0 if assigned to the control group
- $T_{.j} =$ the proportion of sample members in random assignment block j assigned to the program group (i.e., the average value of T_{ij} in random assignment block j)
- $T_{..} =$ the proportion of all sample members randomly assigned to the program group (i.e., the average value of T_{ij} across all sample members)

Results

Program Implementation and Contrast Between Program and Control Conditions

Overall, the program components were implemented with strong fidelity to the model and the experience of the program group was different in anticipated ways from the

[15]Results are nearly identical with or without weights.

experience of the control group, as described in the program model section. Implementation fidelity was assessed based on adherence to the four program components: modular courses, diagnostic assessment, computer-assisted instruction, and on-demand, personalized assistance.

Regarding modular courses, transcript records show that ModMath courses were offered as discrete 5-week, one-credit modules, as planned, and 83% of students in the program group participated in a ModMath course during their first semester post–random assignment. Qualitative data revealed that the ModMath and lecture-based course curricula were aligned, covering the same content. Regarding diagnostic assessment, placement test data indicate that more than 70% of students randomly assigned to ModMath took the MyMathTest diagnostic exam to determine their starting module. Regarding computer-assisted instruction, observational data indicate that ModMath classes were held in computer classrooms and instruction in ModMath classes was delivered primarily via the MyMathLab software. Regarding on-demand, personalized assistance, observational data indicate that each class was staffed with an instructor and aide, who provided individualized assistance to students. Students would request help when needed, but instructors also proactively checked students' work and offered assistance.

In comparison, the control group enrolled in semester-long, three-credit courses. Transcript records show that there was variation in the types of courses control group students enrolled in. Approximately 57% of students enrolled in traditional lecture-based courses, and approximately 20% of students enrolled in one of the non-modularized alternative developmental math offerings, either computer-assisted lecture or Emporium. This is unsurprising as control group students could enroll in any developmental math course type, except ModMath. Table 5 shows the percentage of students who enrolled in each course type. (For simplicity, we have classified computer-assisted lecture and Emporium as non-modularized computer-assisted courses.) Regardless of the type of course in which they were enrolled, all control group students had access to the MyMathLab software package, as the software was required for homework. In addition, students in non-modularized computer-assisted courses used MyMathLab for in-class instruction to varying degrees.

Even though students in both groups had similar access to the instructional software, which somewhat weakened the service contrast between the two groups, classroom observation and student survey data confirm a significant contrast between the classroom experience of ModMath program and control group students. During class, ModMath instructors and assistants focused on providing one-on-one assistance to students who were having difficulty with the course material. They responded to requests for help from students and checked in with students who did not request help, providing unsolicited support. As shown in Table 6, 68% of ModMath survey respondents reported that their instructors spent a considerable amount, or most, of their time working individually with students during class, compared with only 32% of control group students. In contrast, the majority of non-ModMath instructors focused class time on whole-group instruction. Seventy-nine percent of control group survey respondents reported that their instructors spent a considerable amount, or most, of their time lecturing the class, compared with only 23% of ModMath students.

Table 6. Student survey results: Instruction and assistance.

Response (%)	Sample size	Program group	Control group	Difference	Standard error
In your most recent math class, the instructor spent a considerable amount or most of the class period					
Lecturing the class	993	23.3	79.3	−56.0***	2.7
Working with small groups of students	992	22.8	25.0	−2.2	2.8
Working with students individually	992	67.6	31.7	35.9***	3.1
Giving announcements not related to math	989	12.4	14.4	−1.9	2.2
In your most recent math class, the students spent a considerable amount or most of the class period					
Working alone on math exercises	992	80.5	53.6	26.8***	3.0
Working in small groups on math exercises	991	7.3	12.9	−5.6***	2.0
Working as a class on math exercises	990	15.1	60.5	−45.4***	2.9
Chatting, texting, or on personal business	991	4.1	6.3	−2.1	1.5
Using computers, calculators, or technology	993	80.5	57.8	22.6***	3.0
Having problems with technology	993	2.5	5.9	−3.4**	1.3

Note. Total survey respondents $N = 1{,}012$. Total program group respondents $n = 620$. Total control group respondents $n = 392$. Estimates are adjusted by cohort. Rounding may cause slight discrepancies in sums and differences. Distributions may not add to 100% because categories are not mutually exclusive. Calculations made using data from survey of Tarrant County College students.
***$p = .01$; **$p = .05$; *$p = .10$.

Accordingly, there was a significant difference in how students spent their time in math class. ModMath students worked individually on the instructional software. Table 6 shows that approximately 80% of ModMath survey respondents reported spending most of their time in class using computers, calculators, or technology and working alone on math exercises, while close to 60% of the control group reported similar experiences. This was expected given that the question asked whether students used computers, calculators, or technology and students in non-ModMath classes had time allotted for individual and small-group exercises. Generally, control group survey respondents reported more whole-group instruction. Sixty-one percent of the control group report spending a considerable amount, or most, of their time working *as a class* on math exercises, compared with only 15% of the program group.

Taken together, these data highlight that ModMath offered students a more individualized class experience in which students spent significant time working independently on math exercises on their computers or being assisted by the instructor individually. In contrast, non-ModMath instructors spent a considerable amount of time lecturing the class, and students worked as a class on math exercises.

Evidence for ModMath's Theory of Change

We examined whether the expected benefits of certain program components (as outlined in the theory of change) were realized in practice.

Fine-tuned assessment and module placement. Modules in conjunction with the fine-tuned diagnostic exam did *not* allow the majority of ModMath students to bypass already mastered material and start in a higher module. Approximately 84% of students placed at the beginning of the math course sequence under both testing approaches. Since these students likely needed remediation in all the content covered by the developmental math curriculum, the opportunity to place into modules using MyMathTest did not make much of a difference.[16] Relevant context when considering this finding is that when ModMath first began, prior to the present study, TCC offered three developmental math courses and nine ModMath modules. Just prior to the start of the study, the lowest developmental math course was cut from the sequence due to a series of policy changes, and the number of modules was reduced from nine to six. This change may have resulted in a greater number of students beginning the developmental math sequence in the lowest course or module, limiting the potential benefit of the diagnostic assessment.

Modularization and credit retention. As hypothesized (and shown later), the modular structure resulted in greater credit accumulation due to the ability to earn one credit at a time (see Program Effects on Academic Outcomes section below). Focus group data suggest that this resulted in a greater sense of accomplishment. For example, one participant commented: "I've taken many, many remedial classes and haven't gotten anywhere because after a while I realized that I didn't have the core that I needed to move on. I'm almost finished with my college career here at TCC, and the only thing that's holding me back is the math requirements. So I was really upset that I had to start at the bottom [mod], but I will say I passed my first mod with an A, which I've never done that, so something must be working." This illustrates a common sentiment by focus group participants who received transcript credit mid-semester for passing a module. By facilitating these small wins, ModMath is theorized to result in improved developmental math completion. We examine whether this occurred in practice below.

Content mastery. Due to the lack of a common final exam between program and control group students, the current study could not directly assess whether ModMath resulted in improved content mastery. It is important to note that ModMath students could attempt their exams without working through the module content; however, they could not progress to the next module without passing the final exam for their current module.

Self-paced learning and acceleration. Computer-delivered modules are theorized to improve student outcomes because they allow students to work at their own pace and potentially complete more than three modules in one semester. Our analyses revealed that acceleration was possible, but not prevalent. Focus group participants often referred to the self-paced nature of ModMath as being beneficial for the ability to slow down when learning the material, as opposed to accelerating and completing the sequence faster. For example, one student commented that with the video lessons, "you get to stop the teacher and keep going over and over [the material] until you get it, and you won't move on, and you won't get left behind because the teacher or class is moving on." This finding was confirmed by course transcript data, which revealed that more ModMath students repeated modules, as opposed to accelerating and completing more than three modules in one semester (24% versus 1%, respectively). This occurred even though instructors provided students with a pacing calendar that detailed the amount of work they needed to accomplish each day to complete the module in the allotted time frame and the full course by the end of the semester.

Although ModMath did not lead to student acceleration, the self-paced nature of the program may have resulted in students feeling that the difficulty of their course was appropriate. Approximately 71% of program group survey respondents reported that the

[16]MyMathTest did appear to alter placement for 16% of students: Approximately 12% of students placed higher, and approximately 4% of students placed lower than under the college's standard placement exams.

level of difficulty of their math class was just right, compared with 51% of control group survey respondents.

Individualized instruction and student support. Based on interview and focus group data, ModMath increased one-on-one interactions between instructors and students, creating increased opportunities for instructors to provide academic and emotional support to struggling students. ModMath focus group participants frequently juxtaposed their support experience in ModMath with their previous experience in lecture-based courses. For example, one student commented: "It's so much easier than lectures because I don't feel pressure to just hurry up and just understand it … I don't really like asking questions in front of a big group of people because I'm scared I'm gonna ask a stupid question." Most focus group participants felt that ModMath had increased their level of academic and personal support.

In general, ModMath services were largely implemented as planned, and the program provided a notably different developmental math experience for students compared with TCC's traditional lecture-based courses. There is evidence that some elements of theory of change were realized in practice, while others were not. The next section discusses the program's impact on student academic outcomes.

Program Effects on Academic Outcomes

This section presents estimates of the effect of ModMath on students' academic outcomes derived from the college's transcript records and achieved over the course of three semesters after random assignment. Overall, ModMath was no more or less effective than traditional math. After three semesters, 23% of program group members had completed the developmental math sequence, the primary outcome of interest. Similarly, 22% of the control group reached the same milestone. On average, program group members completed a higher proportion of the six-credit developmental math sequence than did control group members. This was largely a result of the structural shift that allowed ModMath students to earn one credit for completing each of the six modules, whereas control group students earned credit only for completing the entire three-credit course. More details are provided below.

Enrollment, Progress, and Completion of Developmental Math

Derived from college transcript records, Table 7 presents information on students' enrollment at college and progress through and completion of the developmental math sequence. Findings are presented for the first three semesters after students were randomly assigned; that is, regardless of cohort of entry, we present findings for each student's first, second, and third semesters after entering the study.[17] Findings are presented semester by semester.

[17]Recall that most program group members needed to pass all six modules and most control group members needed to pass two developmental math courses to complete the developmental math sequence; thus, three semesters provides a reasonable amount of time for students to achieve the goal of completing the developmental math sequence, although many students may take longer in practice.

Table 7. Developmental math progress.

Outcome (%)	Program group ($N = 826$)	Control group ($N = 577$)	Estimated effect	Standard error
First semester				
Enrolled in college	93.1	90.2	2.9*	1.5
Enrolled in any math class (course or mod)	86.7	80.6	6.1***	2.0
Average percentage of developmental math sequence completed	26.4	17.5	8.9***	1.5
Developmental math sequence progress since RA				
Earned at least 1 developmental math credit or higher	69.5	30.0	39.5***	2.5
Completed first half of developmental sequence	27.1	29.8	−2.7	2.5
Completed developmental sequence (college-ready)	2.2	5.1	−2.9***	1.0
Completed a college-level math course	0.4	0.3	0.0	0.3
Second semester				
Enrolled in college	68.7	61.8	6.9***	2.6
Enrolled in any math class (course or mod)	51.4	40.3	11.2***	2.7
Average percentage of developmental math sequence completed	37.9	27.1	10.9***	2.0
Developmental math sequence progress since RA				
Earned at least 1 developmental math credit or higher	72.4	38.4	34.0***	2.6
Completed first half of developmental sequence	40.6	38.2	2.4	2.6
Completed developmental sequence (college-ready)	14.7	15.7	−1.0	1.9
Completed a college-level math course	2.6	2.9	−0.3	0.9
Third semester				
Enrolled in college	51.9	48.8	3.1	2.7
Enrolled in any math class (course or mod)	35.3	29.9	5.5**	2.5
Average percentage of developmental math sequence completed	43.2	32.5	10.7***	2.1
Developmental math sequence progress since RA				
Earned at least 1 developmental math credit or higher	74.4	43.2	31.2***	2.6
Completed first half of developmental sequence	45.7	42.8	2.9	2.7
Completed developmental sequence (college-ready)	22.5	22.0	0.4	2.3
Completed a college-level math course	6.9	9.2	−2.3	1.5

Note. $N = 1{,}403$. RA = random assignment. Estimates are adjusted by cohort. Rounding may cause slight discrepancies in sums and differences. The Fall 2016 cohort has data only for part of the third semester. Calculations made using transcript data from Tarrant County College.
***$p = .01$; **$p = .05$; *$p = .10$.

First semester. Immediately after random assignment, 93.1% of the program group and 90.2% of the control group enrolled at TCC. The difference, 2.9 percentage points, represents ModMath's estimated effect on getting students to enroll in college.[18] There are several possible explanations for this effect. This may reflect program group students' preference for having been given the opportunity to participate in ModMath or control group students' disappointment after not being offered the opportunity to participate in ModMath. Alternatively, it may be the case that ModMath staff were more

[18]Throughout this section the outcomes represent least squares means, and the estimated effect was calculated using a linear regression model. For ease of exposition we refer to *the effect of ModMath*, although technically it is *the effect of the opportunity to participate in ModMath*. Similarly, we refer to *program and control group outcome levels*, although we are presenting *regression adjusted least squares means*.

likely to conduct personal outreach to program group students to ensure they enrolled, than were non-ModMath staff for control group students.

In addition to this small positive effect on enrolling in college, students offered ModMath were 6.1 percentage points more likely to enroll in a math class (a module or a course) than were their control group counterparts.[19] In other words, assignment to ModMath caused an estimated 50 additional students to enroll in math (out of the 826 program group students).[20] This positive effect on attempting any math credits is intriguing, since, as noted by Bailey et al. (2010), "More students exit their developmental sequences because they *did not enroll* in the first or a subsequent course than because they *failed or withdrew from* a course in which they were enrolled."

Notably, to be eligible for the study, students had to be willing to participate in ModMath, and the only way to get into ModMath was to enroll in the study. Students who preferred the traditional math course could simply enroll in it, without participating in the study. Thus, ModMath's positive effect on getting students to take a math class may apply only to the types of students in the evaluation and may not generalize to all students in the college who required developmental math, especially those who preferred the traditional course. Nonetheless, the offer of ModMath encouraged some additional students to at least attempt a developmental math class, which is a strong starting point.[21] However, the goal of ModMath is to help students progress through and ultimately complete the developmental math sequence. We turn to progress and completion next.

Program group students were much more likely to earn at least one developmental math credit (by passing a module or a course) than were their control group counterparts—an indication of at least some degree of progress. Nearly 70% of program group students completed at least one class (typically at least one 5-week, one-credit module), compared with only 30% of control group students (typically a semester-long, three-credit course). This 39.5 percentage point increase in earning at least one math credit occurred largely because ModMath students had the opportunity to pass smaller portions of the developmental math sequence, 5 weeks at a time, one credit at a time. In contrast, students enrolled in the traditional courses were in an all-or-nothing situation—they had to pass an entire 16-week course to earn three credits. This structural difference led to a substantial difference in the number of students who were able to make *some* formal progress in the developmental sequence by accumulating one or more developmental math credits during the first semester.

Relatedly, on average, program group students completed a higher percentage of the developmental math sequence than did control group students. By the end of the first semester, program group students had completed 26.4% of the developmental math sequence, whereas control group students had completed 17.5% of the sequence—for an estimated effect of 8.9 percentage points. The positive effect on the percentage of the developmental math sequence completed is also due, in large part, to program students

[19]Note that 0.6% of program group members and 0.3% of control group members enrolled directly in a college-level math course in their first semester after random assignment.

[20]Calculated as $826 \times 0.061 = 50$.

[21]Like the small effect on initial enrollment in college, the reason for the positive effect on attempting a developmental math course is not certain. It may have been due to the appeal of the program, but it also may have been an artifact of the experiment.

earning credit for completing one or two modules in a semester, rather than having to complete an entire three-credit course.[22]

ModMath's positive effect on completing at least one math credit and on the percentage of the developmental math sequence completed is encouraging. However, this success is tempered by the fact that only 27.1% of the program group completed the first half of the developmental sequence (Mod 3) by the end of the first semester. Students in the traditional math sequence had a similar likelihood of success: 29.8% of the control group made it through the halfway point (Math 0361) in one semester. The negative 2.7–percentage point estimated effect is not statistically significant, but it is discouraging. Moreover, there is evidence that ModMath lowered the proportion of students who completed the developmental sequence (and were thus college-ready) during their first semester. Only 2.2% of program group students accomplished this goal, compared with 5.1% of control group students, for an estimated effect of negative 2.9 percentage points, representing around 24 people.

In sum, after one semester the effects of ModMath were mixed. The program helped students make greater progress on average, but program group students were no more likely than control group students to reach the halfway milestone, and they were slightly less likely to complete the full developmental math sequence. Does the "early win" of earning at least one math credit, achieved by nearly 70% of the program group, translate into larger gains in future semesters? We turn to this next.

Second semester. ModMath increased second-semester enrollment by an estimated 6.9 percentage points. The program group's second semester enrollment rate was a disappointing 68.7 percent, implying a high level of dropout (or stop out); however, this rate is encouragingly significantly higher than the control group's enrollment rate. Much like the first semester enrollment effect, this finding may have to do with program group students' positive experiences in ModMath or the control group's disappointment of not being offered ModMath. In this case, the effect estimate is positive and highly statistically significant ($p = .008$), so it is unlikely a chance finding. Notably, part of this effect is driven by the 7.2% of program group members who only enrolled in a math class (compared with 3.1% of the control group). This may suggest that the overall enrollment effect is partially driven by structural differences, like the fact that the census date for the first Mod was one week into the semester and the census date for regular courses was two weeks into the semester. However, among those program group students whose only class was math ($n = 60$), 70% earned one or more credits and 43% earned two or more credits. That is, most program group students who enrolled only in math did accomplish something; they did not simply enroll and then drop out after the census date. So, the overall enrollment effect appears to be a bright spot in an otherwise sobering story.

Regarding math progress and completion, during the second semester program and control group students continued to make progress. On the positive side, ModMath again caused more students (11 percentage points) to enroll in a math class; students offered ModMath remained much more likely (34 percentage points) to have earned at least one math credit since the start of the study; and the program group maintained its advantage with respect to the percentage of the developmental course sequence

[22]Recall that control group members can only be 0%, 50%, or 100% complete, whereas program group members can be 0%, 33%, 50%, 67%, 83%, or 100% complete.

completed (10.9 percentage points). However, ModMath had no discernable effect on causing students to achieve the key milestones of completing the first half of the developmental math sequence or completing the entire sequence and thus being deemed college-ready in math. Lamentably, only around 15% of the 1,403 students in the study became college-ready in math within two semesters. Most students either did not attempt all required developmental math courses/modules, failed one or more courses/modules, or did not reenroll at TCC.

Third semester. Students were tracked through three semesters after they entered the study. Students in ModMath and the more traditional math course had almost identical rates of completing the developmental math course sequence (22.5% vs. 22.0%, respectively). This occurred even though program group students continued to attempt a math class (course or module) at a higher rate than their control group counterparts, and they maintained their advantage with respect to the percentage of the developmental math sequence completed. Nonetheless, when it came to three major milestones—completing the first half of the developmental math sequence, becoming college-ready in math, and passing the first college-level math course—there was no discernable difference between the outcomes of students offered ModMath and their control group counterparts.

Non-Math Progress. Table 8 examines non-math credits attempted and earned through three semesters. We find no evidence of any discernable positive spillover effects or negative unintended consequences of ModMath.

Subgroup Findings

In addition to examining ModMath's overall average effects, we explored the programs' effects for different types of students—specifically, with respect to students' baseline comfort with technology, developmental need, intent to enroll full time, and intent to work full time—all of which were measured prior to random assignment. Table 9 presents findings by subgroup. For example, the first panel shows that ModMath's estimated effect on becoming college-ready in math after three semesters is 1.0 percentage point for students who self-reported being comfortable with technology at the start of

Table 8. Cumulative non-math progress.

Outcome	Program group ($n = 826$)	Control group ($n = 577$)	Estimated effect	Standard error
One semester				
Non-math credits attempted	6.49	6.56	−0.07	0.22
Non-math credits earned	4.82	4.73	0.10	0.23
Two semesters				
Non-math credits attempted	11.76	11.67	0.10	0.43
Non-math credits earned	8.64	8.49	0.14	0.42
Three semesters				
Non-math credits attempted	15.49	15.16	0.33	0.61
Non-math credits earned	11.44	11.14	0.30	0.58

Note. $N = 1{,}403$. Estimates are adjusted by cohort. Rounding may cause slight discrepancies in sums and differences. The Fall 2016 cohort has data only for part of the third semester. Calculations made using transcript data from Tarrant County College.
$^{***}p = .01$; $^{**}p = .05$; $^{*}p = .10$.

Table 9. Percentage of students ready for college math in the third cumulative semester.

Student characteristic	Sample size	Percentage of students ready for college math: Program group	Control group	Estimated effects	Standard error	p value for estimated effects	p value for differential estimated effects
Comfort with computers at baseline[a]							.867
Comfortable	1,023	22.3	21.3	1.0	2.6	.709	
Not comfortable	362	23.8	23.7	0.1	4.5	.982	
Sample size	1,385						
Number of levels placed below college math[b]							.115
1 level below or higher	221	31.3	33.5	−2.2	6.4	.729	
2 levels below	190	21.6	29.9	−8.3	6.4	.194	
3 levels below	541	20.2	14.4	5.7*	3.3	.084	
Sample size	952						
Intended to enroll full time at baseline[c]							.950
Full time	594	24.7	24.0	0.7	3.6	.845	
Not full time	777	21.4	20.4	1.0	2.9	.734	
Sample size	1,371						
Intended to work full time at baseline[d]							.585
Full time	609	18.3	18.9	−0.6	3.2	.863	
Not full time	432	26.7	24.4	2.4	4.2	.579	
Sample size	1,041						

Note. Sources: MDRC calculations using data from the baseline survey of Tarrant County College (TCC) students, TCC placement test data, and TCC transcript data.
Rounding may cause slight discrepancies in sums and differences.
Estimates are adjusted by cohort.
A two-tailed *t* test was applied to differences between research groups. Statistical significance levels are indicated as: *** = 1%; ** = 5%; * = 10%.
A two-tailed *t* test was applied to differences of impacts between subgroups. Statistical significance levels are indicated as: ††† = 1%; †† = 5%; † = 10%.
The Fall 2016 cohort only has data for part of the third semester.
A student is defined as ready for college math when the student either passed the final course in their developmental math sequence or a college-level math course.
[a]Comfortable with technology defined as students who responded as being "extremely comfortable" or "comfortable" when asked "how comfortable are you using computers to do school work?"
[b]Determined by the Texas Success Initiative (TSI) placement test. One level below or higher includes students who are TSI exempt or waived, previously met TSI requirements, and placed into college math or one level below college math.
[c]Intent to enroll full time defined as a student's intent to enroll in 12 credit hours or more during the semester in which they were randomly assigned.
[d]Intent to work full time defined as a student's intent to work 30 hours or more per week during the semester in which they were randomly assigned.

the study and 0.1 percentage points for students who were not. The final column in the table, with p value 0.867, shows that these two effect estimates are not statistically distinguishable. Stated differently, the 0.9 percentage point difference $(1.0 - 0.1)$ in effect estimates between these two groups could easily have occurred by chance if the program's true effects were the same for both groups. The rest of the table shows that there is not clear evidence that ModMath was more effective for any subgroups of students: Effect estimates are mostly near zero, just like the overall average.

In summary, breaking the developmental math course sequence into six one-credit, computerized modules led ModMath students to make incremental progress toward completing the sequence. Despite this apparent advantage, the ModMath program is no more (or less) effective than the traditional developmental math course at helping students complete their developmental math requirements.

Limitations

This study is one, if not the only, experimental evaluation of a modularized, computer-assisted, self-paced developmental math program in a community college setting. As a result, it provides an internally valid estimate of the causal effect of such a program on students' completion of the developmental math course sequence.

One important limitation of the study is that we are unable to assess ModMath's effect on mastering course content since program and control students did not take a common standardized exam or posttest and it was beyond the scope of the project to ensure that they did so. This is a common challenge in postsecondary research, where truly standardized outcomes are rare. That said, upon completing the developmental math course sequence, program and control group students could enroll in the same college-level math courses, at which point any deficit or benefit with respect to content knowledge could result in higher pass rates; we do not observe any program effects on passing college-level math courses.[23]

Another limitation is that the present study's findings are specific to ModMath at TCC and may not generalize to other colleges with different institutional contexts, different alternative course offerings, or drastically different student populations. Moreover, students could enroll in ModMath only if they joined this study, while students could enroll in other course types without restriction. As a result, the findings presented here do not necessarily inform whether ModMath would be well suited for students with a strong preference for traditionally structured lecture classes; such students could experience ModMath differently and therefore have different academic outcomes.

Finally, we did not conduct a formal cost analysis as part of this project. Nonetheless, with respect to cost, it is worth noting that ModMath likely costs a little more than the traditional math class. Although ModMath and traditional math classes were of similar class size, and both offered the use of instructional software, only ModMath included an

[23]The TCC math department staff, who developed ModMath and operate the other math course options, consider completion of each of the various alternative course sequences to be equivalent. A standard curriculum was used for all the college's developmental math course sequence options (including ModMath), and completing any option enables students to meet an institutional requirement. Moreover, since the overall conclusion is a story of null effects, the standards across treatment and control groups would have to be large to substantially change the findings. Given that the intention of the math department is to keep the standards the same, this may not be likely.

instructor and an instructor's aide. The additional cost per student for an aide is an important consideration when interpreting the findings from this study.

Discussion

Increasing the academic success of students referred to developmental math courses is a pressing priority for community colleges. Modularized, computer-assisted, self-paced remedial math courses, such as ModMath, are a widespread reform currently being implemented at institutions across the nation, yet limited rigorous evidence on the efficacy of this approach exists. The present study employed a randomized controlled trial to evaluate ModMath and found that ModMath is similarly effective at getting students through the developmental math sequence as other course formats, particularly traditional lecture-based courses.

Sometimes when an evaluation finds that an intervention was no more or less effective than the alternative, the lack of impact can be attributed to poor program implementation or a weak contrast between the program and control groups. This was not the case in this study: For the most part, the program services were implemented as planned by its designers and there were significant differences between the classroom experiences of ModMath and control group students. Given this, we look to the theory of change for insight into the findings.

One potential explanation for ModMath's lack of positive impact is that some elements of the theory of change that were theorized to lead to improved student outcomes were not realized in practice. The fine-tuned diagnostic exam did not change placement for the majority of ModMath students; the self-paced modules did not result in student acceleration; and the small wins gained by earning credits incrementally did not increase completion of the developmental math sequence. We discuss each of these, in turn.

With regard to the diagnostic exam, it is possible that the curricular changes that shortened the developmental math sequence from three to two courses just prior to the start of the study muted the potential benefits of the fine-tuned assessment. As a result, the college may consider alternative placement methods. Many institutions are beginning to rely on multiple measures to assess student readiness for college-level work, instead of relying on a single exam, and recent studies have shown that this reform may improve students' outcomes in math (Barnett et al., 2018; Scott-Clayton & Belfield, 2015). For TCC, incorporating multiple measures of assessment (in addition to a placement exam) may better identify students who would succeed in a higher developmental math module or course.

With regard to self-pacing, we find that more ModMath students slowed down as opposed to accelerated, which is consistent with other research on self-paced computer-assisted courses and may be relevant beyond developmental math education. There is a tension among autonomy, mastery, and acceleration in self-paced, modularized courses (Bickerstaff et al., 2016). Mastery learning requires students to meet certain benchmarks before moving forward in the curriculum, which will naturally lead to slower progression. Furthermore, since many developmental math students have a history of underperformance in math, and many community college students manage school with work and other personal responsibilities, such as childcare, the flexibility offered by a self-paced course makes it more likely that these students will progress more slowly as opposed to more quickly. While ModMath designers attempted to overcome this challenge by issuing pacing calendars to keep students on track, acceleration was not explicitly promoted. To promote acceleration in ModMath, and other self-paced courses, while addressing the academic and personal needs of developmental math students in community colleges, a triage approach may be necessary. Students who are more advanced or have more available time could be identified and explicitly encouraged to move faster, through personalized pacing calendars or other means.

Alternatively, developmental math acceleration strategies that tailor and align required content to student's academic interests, as opposed to expecting students to cover more material in less time, may be more feasible. These types of strategies are gaining in popularity and some are showing early signs of success. For example, a study on the Dana Center's Math Pathways program, which reduces the required number of developmental math courses based on program of study, has shown early signs of positive impacts on college readiness (Zachry Rutschow, 2018). Similarly, a randomized controlled trial of an initiative that shifted required course content, from a prerequisite elementary (remedial) algebra course to statistics with co-requisite remediation that only addresses the math needed for the statistics course, for students in non-STEM (science, technology, engineering, and mathematics) majors is gaining in popularity, and at least one randomized trial finds evidence of improved outcomes (Logue, Watanabe-Rose, & Douglas, 2016).

Regarding modularization, we find that ModMath's modular course structure resulted in greater credit accumulation and increased feelings of accomplishment for students, but these small wins were not enough to get students to the finish line. The fact that only about 22% of students in either group completed the two-semester developmental math sequence in three semesters indicates that far too many students are struggling using either approach.

Given this, the fact that higher education institutions are searching for ways to get students through the developmental math sequence faster, and early experimental research showing more positive results for other types of interventions (Barnett et al., 2018, Logue et al., 2016; Scrivener et al., 2018; Zachry Rutschow, 2018), ModMath is not currently the most promising strategy for developmental math reform. It is, however, an alternative to traditional lecture-based courses that leads to similar outcomes. Thus, to accommodate individual student preferences, colleges could offer ModMath and expect similar results as lecture-based courses.

Open Scholarship

This article has earned the Center for Open Science badge for Preregistered. The materials are openly accessible at https://sreereg.icpsr.umich.edu/framework/pdf/index.php?id=2351.

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