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How Maryland's Mathematics Reform Initiative Shapes Student Success: Lessons from Maryland's Community Colleges

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How Maryland's Mathematics Reform Initiative Shapes Student Success: Lessons from Maryland's Community Colleges

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Remedial/developmental education in college, which aims to provide learning support to students assessed as not college ready, can become a roadblock impeding students from retaining and completing college. Starting in 2000, various reforms were implemented nationwide to explore an effective approach to remove barriers, accelerate time of remediation and boost learning outcomes. Maryland is one of the states leading the reforms. In 2013, the University System of Maryland led Maryland's Mathematics Reform Initiative (MMRI), a collaboration among seven Maryland community colleges[4] and five state public four-year institutions[5] to redesign the math pathway in higher education in order to make the remedial math courses relevant for students' chosen career paths. This policy brief evaluates the impact of this math pathway reform on Maryland community colleges students. The analysis on public four-year institutions will be forthcoming.

Introduction

Successful completion of gateway math, the first credit-bearing college-level math course required by degree programs, is a critical academic milestone for community college students. However, many new students are assessed as requiring developmental (or remedial) education to strengthen their math knowledge and skills for college-level math. In Maryland approximately 60 percent of community college students entering in 2016 were identified as needing developmental education in math[6].

Traditionally, students entering community colleges who need math remediation are required to complete a remedial math course on an algebra track for one semester or one year, such as intermediate algebra, geometry, and trigonometry, before enrolling in college-level math. The developmental math sequence consists of algebra-based courses designed to prepare students for college algebra and, eventually, calculus. However, this curriculum has been criticized for its poor alignment with the math skills relevant to students' majors, jobs, and everyday lives (e.g., Cullinane & Treisman, 2010; Hern, 2010). To address this issue, math pathways have gained popularity as a reform to improve success in college-level math (Burdman et al., 2018).

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[4] These seven are Anne Arundel Community College, Cecil College, College of Southern Maryland, Garrett College, Harford Community College, Howard Community College, and Montgomery College.
[5] These five are Towson University, University of Baltimore, University of Maryland, Baltimore County, and University of Maryland Global Campus.
[6] Maryland Higher Education Commission, October 2024. Remediation Education in Maryland Public Institutions. Baltimore, MD: Maryland Higher Education Commission.

Put simply, math pathways are structured sets of math courses that align with a student's academic goals; instead of a one-size-fits-all approach where all students take the same courses, pathways are more tailored. Currently adopted by over 20 state college systems (Education Commission of the States, 2021), these reforms provide alternative, non-algebra options, such as statistics or quantitative reasoning, for students not interested in pursuing the degrees that require algebra-track college math such as STEM (Science, Technology, Engineering and Math) majors. The goal is to offer students multiple pathways through the math curriculum, instead of making all students to complete a single pathway.

The MMRI project was built upon the same theory – the math content students are learning can be disconnected from the math they need to be successful in coursework and their major areas of study (Shapiro, 2016).

This report explores three key questions: (1) What are the effects of Maryland's math reform (MMRI) on developmental and college-level math completion in Maryland community colleges? (2) How do changes to math curriculum and other components influence these effects? (3) How does MMRI affect students' likelihood of entering into or progression through STEM pathways? To rule out the confounding impacts from the other factors and obtain causal effects of the reform, the study employed a difference-in-differences approach, comparing student outcomes at MMRI-participating colleges to the non-participating colleges before and after the reform.

Background

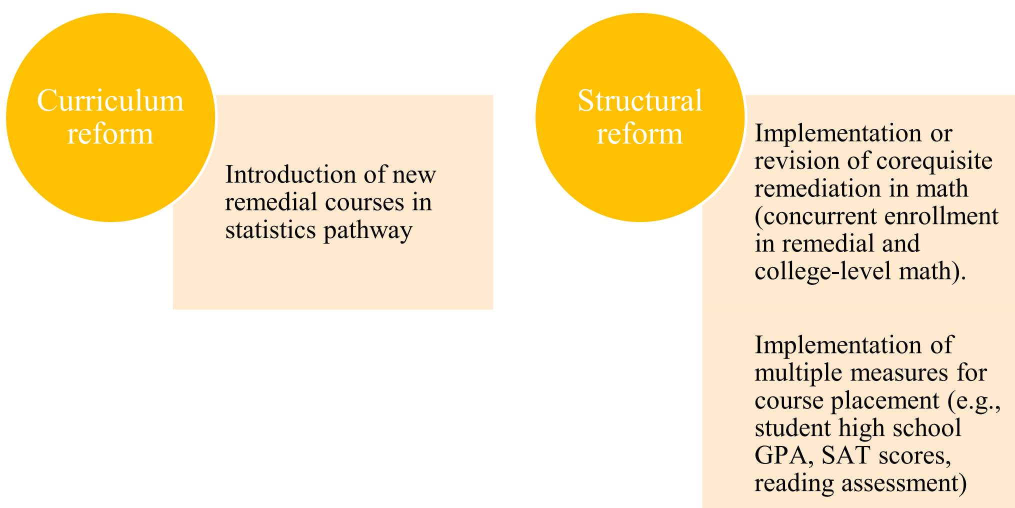
In 2013, Maryland's General Assembly passed the College and Career Readiness and College Complete Act (CCR-CCA), which required all Maryland public higher education institutions to develop a pathway system establishing graduation benchmarks and ensure students enroll their credit-bearing mathematics and English general education courses within the first 24 credit hours of study. As a result, the University System of Maryland (USM) created the Maryland Mathematics Reform Initiative (MMRI) to explore the system changes that are needed to improve success for students in math and degree completion. In 2015, the initiative received a five-year grant from the U.S. Department of Education's First in the World (FITW) program. Collaborating with 12 public institutions (five public four-year institutions and seven community colleges), the MMRI FITW (MMRI thereafter) project conducted a comprehensive reform to design alternative developmental math that involved advisors, counselors, and faculty. Later on, USM extended the project convening and professional development to the other public and private institutions that were not funded by the project but planned to adopt similar reforms to their remediation education.

Before 2016, it was regulated in Maryland that general education programs of public institutions shall require one course in mathematics at or above the level of college algebra (Code of Maryland Regulations, 13B.06.01.03, 2016). Back then, all students who were assessed below college readiness were expected to complete the algebra-track math sequence. In 2016, the regulation was amended for general education math as a result of CCR-CCA. To fulfill the general education math requirement, after 2016, students were expected to complete "*one course in mathematics, having performance expectations demonstrating a level of mathematical maturity beyond the Maryland College and Career Ready Standards in Mathematics (including problem-solving skills, and mathematical concepts and techniques that can be applied in the student's program of study)*" (Code of Maryland Regulations, 13B.06.01.03, 2024).

Seven community colleges were part of the inaugural members of the MMRI project, which followed the model of the Dana Center Mathematics pathways (DCMP) and developed a series of interventions that focus on a rigorous pathway in statistical reasoning. The key components of the DCMP are to ensure math pathways aligned with students' goals, accelerate the sequence, integrate student learning support, and utilize evidence-based pedagogy. As such, he the new statistics pathways were designed to be more appropriate, relevant, and useful for students who have not declared a major or whose college major where an introductory college-level statistics course can fulfill the general education requirement (Dana Center, 2019).

The interventions these seven colleges implemented could largely be placed into two categories: (1) curriculum reform: referring to the efforts designing new developmental math courses for students on the statistics pathway; (2) structural reform: referring to the efforts revising how developmental education programs were organized. The latter included components such as revising the placement assessment for math college readiness and allowing developmental students to enroll directly in college-level statistics while receiving concurrent academic support instead of requiring a prerequisite developmental math sequence before students could enroll in gateway math courses (also known as corequisite remediation model).

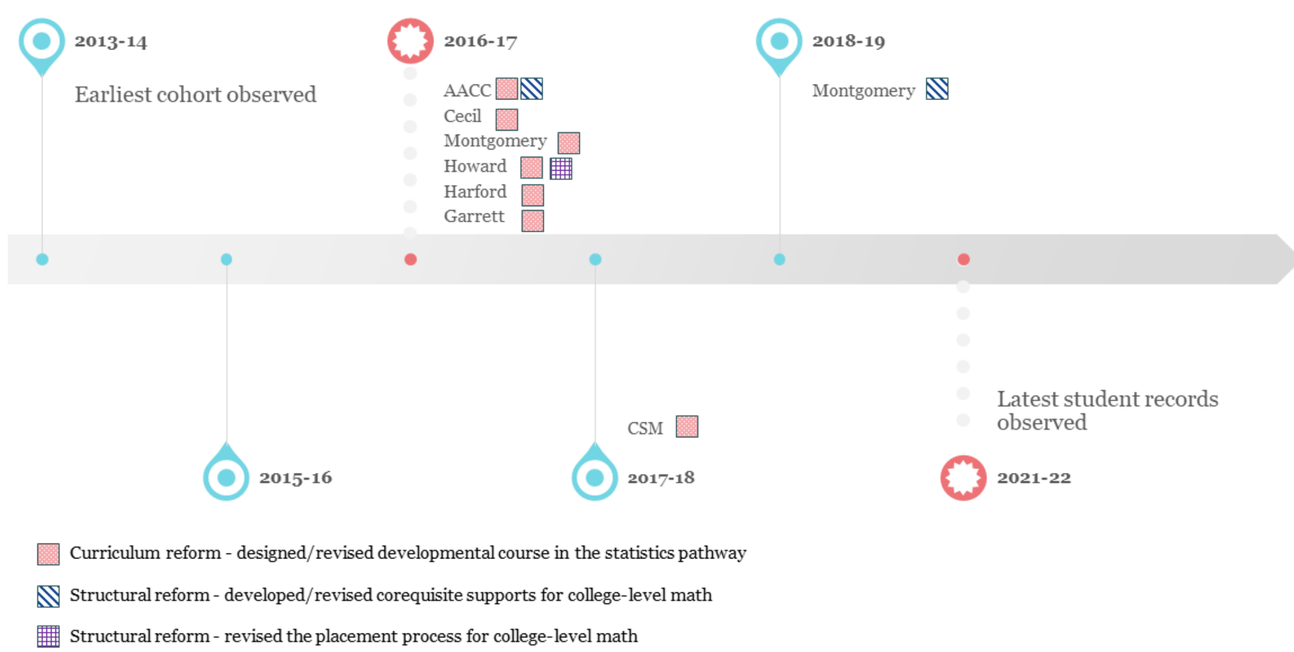
Figure 1. Key Elements of Two Reform Categories



All seven MMRI-participating community colleges implemented the curriculum reform to introduce a new developmental statistics pathway. Figure 2 illustrates the timeline and reform features for the MMRI. Six colleges initiated the new pathway since academic year 2016-17, and another college did so in academic year 2017-18. AACC, Montgomery, and Howard implemented the structural reform on top of the statistics pathway. Among them, AACC and Howard introduced corequisite support and/or revision to developmental placement in 2016, at the same time as the statistics pathway introduction; Montgomery implemented the structural reform components in 2018, two years after the math pathway reform.

In addition to reforming math courses, MMRI colleges are enhancing their efforts in various areas to ensure the successful implementation of the core reform. They have established statewide advisory groups and involved faculty to align the objectives of different pathways with the programs of study. They have developed common curricular materials that can be shared among institutions, created standardized advising resources for students, and provided modular content support tailored for students in different pathways.

Figure 2. Timelines of Maryland Math Reform Initiative (MMRI)



Analysis

The analysis focused on freshmen who entered one of the 16 community colleges in Maryland between academic years 2014-15 to 2019-20. All students were tracked through summer 2021, at least two years after their initial term of enrollment. The final analysis focused on around 89,300 students in the seven MMRI (reform) colleges and 59,900 students from six non-MMRI colleges (non-reform)[7].

Table 1. Summary Statistics

	MMRI colleges	Non-MMRI colleges
Student characteristics		
Female	51.7%	55.3%
Citizen	93.7%	95.7%
Race		
Asian	7.1%	3.8%
Black	25.0%	36.0%
Hispanic	15.1%	6.4%
Other race	11.3%	8.2%
White	41.5%	45.6%
Not active military or veteran	97.6%	97.6%
Maryland residence	93.8%	94.4%
County residence	82.6%	75.7%
Required to take dev-ed math	49.3%	60.0%
Fulltime in 1st term	50.1%	45.1%
SAT math	533	518
High school GPA	3.09	3.03
Outcomes		
% Enrolled in aligned dev-ed-to-gateway sequence		
Before MMRI	29.2%	18.6%
After MMRI	37.1%	16.7%
% completed remedial math requirement by Y1		
Before MMRI	20.8%	27.2%
After MMRI	22.8%	24.8%
% completed gateway math requirement by Y1		
Before MMRI	15.0%	17.3%
After MMRI	21.0%	19.8%
N	89,300	59,868

[7] Three colleges (Hagerstown Community College, Prince George Community College, and Wor-Wic Community College.) that were not initially funded by the MMRI project adopted similar reforms to their developmental math programs during the period of our study. To estimate the effect of the MMRI compared to the non-reform institutions,, the three colleges were dropped them from the analysis.

Directly comparing the student's outcomes between MMRI and non-MMRI does not lead to a causal conclusion because of the underlying differences between the MMRI colleges and non-MMRI colleges. Table 1 presents the student characteristics by MMRI and non-MMRI institutions, which reveals that students are comparable for some characteristics (e.g., gender, military status) but not comparable for other characteristics (race/ethnicity). Most notable for this report is the developmental math rates; reform colleges (MMRI colleges) had higher rates of students ready for college-level math than non-reform colleges.

Since three out of the seven MMRI-participating colleges implemented structural reform (corequisite and revised placement process) to their developmental math programs on top of introducing alternative math pathways (curriculum reform), this study was also able to examine which reform components drove the overall reform effect, and for which student outcomes. More details about the methodology are available in the Technical Appendix. [8]

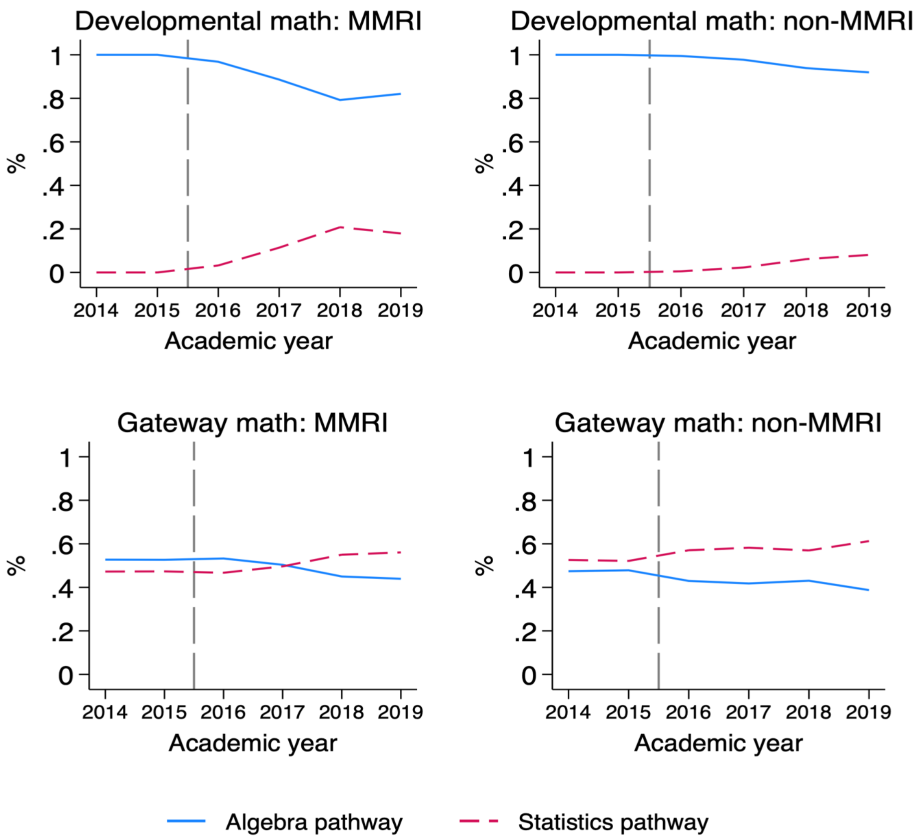
Finding 1: First-year developmental math enrollment and completion increased when aligned with its subject-related college-level math pathway (e.g., developmental statistics aligned with college-level statistics).

Figure 3 shows the proportion of students enrolling in developmental math courses and gateway math courses by Algebra and Statistics[9] pathway for academic years between 2014-15 to 2019-20. For MMRI institutions, there was a marked increase in the percentage of students taking statistics developmental courses after reform efforts were put in place. Before the MMRI reform, all developmental math was on the algebra-based pathway at the participating institutions. In 2016, 13% of developmental math courses were on the statistics pathway at the MMRI participating colleges, and the proportion rose to close to 20% by 2019. There is little change of patterns for those institutions not participating MMRI. By academic year 2019, around 4% of developmental math were on the statistics pathway at these colleges. While MMRI at the community colleges focused on revising developmental math curriculum and structure, the analysis also found an upward trend in the proportion of students taking gateway math on the statistics pathways: at MMRI-participating colleges, the proportion increased from 47% before the reform to 54% after the reform; at non-MMRI colleges, a similar increase from 52% to 59% was observed. We speculate that this is because some non-MMRI institutions, although not officially part of the initiative, have independently adopted or expanded courses on statistics pathways in response to the new general education math requirement.

[8] This study adopted a difference-in-differences (DID) approach to estimate the causal impacts of MMRI on a set of student outcomes. Beside the overall impacts, the study also attempts to disentangle the effects of different components of the MMRI – curriculum reform and structural reform.

[9] Developmental math courses on the algebra pathway include Arithmetic, Beginning Algebra, Intermediate Algebra, or Learning Support for College Algebra. Gateway math course on the algebra pathway include College Algebra, Algebra and Trigonometry, Precalculus, and Calculus. Developmental math courses on the statistics pathway include Pre-Statistics, Quantitative Foundations, or Learning Support for Statistics. Gateway math courses on the statistics pathway include Elementary Statistics, Introduction to Statistics, or Quantitative Reasoning.

Figure 3. Proportion of student course enrollments by math pathway at Maryland community colleges over time



Notes: vertical dash line present the time when MMRI was implemented.

One of the main goals of MMRI reform was to strengthen the alignment of math course content between the developmental math courses and the related college-level math courses so if a student had to take both as a sequence they would have a better chance to complete the developmental course and pass the gateway math course (for this report, this is called the development-to-gateway sequence).

By examining students' likelihood of enrolling in a developmental-to-gateway sequence with aligned curriculum, the quasi-experimental results show (Table 2) that MMRI reform led to a significant increase in this outcome by 10.8 percentage points, representing a 37.% increase compared to the pre-reform proportion of students in such aligned sequences (see the pre-reform level in Table 1). Overall, these results suggest that, at MMRI-colleges, students were much more likely to enroll in developmental math courses that offered appropriate content and curriculum matched with those they needed for the college-level math.

In addition to the enrollment in developmental math courses, the study also found a positive impact on the completion of developmental math. Results in Table 2 suggest that MMRI reform led to a 7.5 percentage point increase in first-year developmental math requirement completion, an equivalent of a 36% increase compared to the pre-reform level.

Table 2. Estimated effects on developmental math enrollment and completion

Outcomes	MMRI Overall
% enrolled in aligned developmental-to-gateway sequence	0.108**
% completed developmental math requirement by year 1	0.075*

Finding 2: *First-year gateway math completion improved when both pathways and corequisite remediation were employed.*

Because of the crucial role of gateway math in college success and failure, the main goal of MMRI was to help students pass the first credit-bearing course in a given math sequence. As shown in Column 1 of Table 3, since the MMRI reform, participating colleges experienced a small but statistically insignificant increase in first-year gateway course enrollment and completion. Put another way, although there are differences in the data over time, the differences are not significant enough to be credited to the MMRI reform. When analyzing the different components of reform, it is clear that institutions implementing structural reform components (such as corequisite courses) have positively impacted gateway math enrollment and completion rates, while institutions implementing curriculum reform alone do not have a significant impact. Table 3 Column 2 and 3 shows these results by separating the effect by different components of the MMRI (curriculum or structural reform).

Structural reform components like corequisite led to statistically significant improvements in both math gateway course enrollment (5.2 percentage points, or 24% increase compared to the average math gateway course enrollment rates before the reform) and math course gateway course completion (4.1 percentage points, or 27% increase compared to the average math gateway course completion rates before the reform). This is probably attributed to the fact that structural reform such as providing corequisite support led to significantly more students enrolling in gateway math during their first year. One common criticism of structural reform is that it allows students who are assessed as not being college-ready to enroll in college-level courses, which can lead to them being unable to complete those courses. However, since the results show that students in institutions that implement structural reforms are also more likely to complete gateway math courses in their first year, it indicates that those who can only enroll in gateway math due to these reforms are still able to successfully complete the course and earn credits.

Table 3. Estimated effects on college-level gateway math enrollment and completion

Outcomes	MMRI Overall (1)	Curriculum Reform (2)	Structural Reform (3)
% enrolled in gateway math by year 1	0.012	-0.003	0.052***
% completed gateway math by year 1	0.015	0.003	0.041***

Finding 3. MMRI reform does not negatively impact the number of enrollees who passed algebra course, while it significantly enhances the number of enrollees who passed statistics course.

Another criticism about the math pathway reforms is that developmental students enrolled in a gateway math course may struggle to pass the course without completing traditional algebra-track remedial education (e.g. Intermediate Algebra). To examine whether students' course performance experienced any changes due to the various reform components, the study also explored the change in gateway math course pass rates - among enrolled students, how many passed the gateway math course. Overall, as shown in Table 4, curriculum reform increases the gateway math course by 3.2 percentage points, an equivalent of 5.9% increase compared to the average gateway math passing rate of 71.4% before the MMRI reform (Row 1 Column 1). As expected, the increases were mostly driven by the improvement in passing rates for gateway courses on the statistics track (Row 3 Column 1). It is likely because the newly designed developmental math in statistics remedies the misalignment between the algebra-track developmental math and college-level statistics that students faced before the MMRI. In contrast, the structure reform components did not have much influence over these outcomes (Column 2).

Table 4. Estimated effects on pass rate of college-level gateway math

Outcomes	Curriculum Reform (1)	Structural Reform (2)
Pass rate of gateway math	0.032**	-0.012
Pass rate of gateway math - algebra	-0.006	0.035
Pass rate of gateway math - statistics	0.047*	-0.043

Finding 4: *MMRI reform has no statistically significant effect on other outcomes like selecting a STEM major, staying in college, or transferring to a four-year institution.*

Another common debate of diversifying math options to fulfill general education requirements is that striking the algebra requirement may simply be the easy way out and divert students away from entering STEM programs. Therefore, this report further examined whether MMRI affected students' major selection and total amount of math course enrollments. The results are presented in Table 5.

In summary, the study did not find evidence to support the hypothesis that students strategically avoided entering a STEM program upon initial enrollment in order to avoid taking math courses on the algebra-to-calculus track. Similarly, there is no evidence that the MMRI reform affected students' major declaration or the total number of college-level math students enrolled by the end of second year. In addition, the MMRI reform did not affect students' overall enrollment persistence or their likelihood of transferring to a four-year university within the state of Maryland. It appears that the MMRI's effects were limited to those outcomes directly related to developmental and gateway math.

Table 5. Estimated effects on major declaration, persistence and transfer

Outcomes	MMRI Overall (1)	Curriculum Reform (2)	Structural Reform (3)
STEM major during first term	0.025	0.019	0.020
STEM major by Year 2	0.015	0.013	0.005
Total number of college-level math completed by Year 2	0.021	-0.007	0.001
Persistence by Year 2	0.003	0.001	0.004
Transfer to 4-year by Year 2	-0.001	0.002	-0.002

Conclusion and Policy Implication

One of the key findings is that the positive effects of the MMRI project were primarily driven by structural reform components. Colleges that implemented statistics pathways with corequisite support and revised course placement procedures saw significant improvements, with a 5-percentage-point increase in gateway math enrollment and a 4-percentage-point increase in gateway math completion. This outcome aligns with evidence from the other states – developmental math education reform is most effective when it allows students to enroll in college-level math as soon as possible[10].

However, the findings indicate that expanding math pathways alone did not improve overall gateway math completion rates. A few factors identified in previous literature

[10] Corequisite support allows remedial students to engage in college-level study while concurrently receiving the assistance they need. Evidence from various contexts, such as CUNY and community colleges in Texas and Tennessee, consistently demonstrates that the corequisite approach is more effective in helping students complete their first college-level math course (e.g., Logue et al., 2016; Logue et al., 2019; Meiselman & Schudde, 2022; Miller et al., 2021; Ran & Lin, 2022).

on student success in community colleges and instructional methods might help explain this lack of significant effects.

First, achieving significant academic milestones, such as completing the gateway math requirement, often depends on factors beyond classroom, particularly at community colleges. External challenges, such as employment or childcare responsibilities, can interfere with students' continued enrollment (CCCSE, 2012; Johnson et al., 2010). While the redesigned developmental math curriculum may enhance course performance for students attending classes—as evidenced by improved grades in gateway math courses—it does not address the external factors that prevent some students from enrolling, which limits the overall impact on gateway math completion rates.

Moreover, curriculum reform, coupled with the pedagogical innovations it often entails, typically addresses specific issues within the teaching and learning environment. The Dana Center Math Pathways model's theory of change, for example, posits that math pathways aligned with fields of study improve student outcomes by fostering greater content mastery, deeper engagement, and a clearer understanding of math's relevance to real life and careers (Sepanik & Barman, 2023). These nuanced effects are often challenging to capture through standard administrative data metrics.

This study found that math pathway reforms did not deter students from pursuing STEM programs or enrolling in advanced math courses beyond the gateway level. Research on the implementation of math pathway reforms reveals that students often gather information from multiple sources when deciding which courses to take and which instructors to choose (Purnell & Burdman, 2021). In this process, ensuring students have access to counseling or advising is essential to guide them toward their desired fields of study and corresponding math pathways. A key activity of the MMRI was developing and validating standardized advising materials accessible online or through institutional resources to ensure students receive advising support (Morgan, et.al., 2019). This proactive approach to advising likely contributed to the MMRI's success in preventing unintended consequences, such as diverting students away from STEM programs.

This report highlights several key directions for policy and practice in developing effective math pathways reforms.

Maryland colleges can focus on removing barriers that prevent students from taking college-level math in their first year. As found in the study, simply offering a developmental (remedial) statistics course doesn't improve enrollment or success in college math. Colleges that made both curricular and structural reform saw improvements. As many Maryland community colleges have implemented already, a multiple-measures approach, which considers factors such as high school GPA and course records rather than relying solely on standardized placement tests is proven to be an effective approach for assessing student's college readiness more accurately. By placing many students who would have been assessed as not college ready by the sole standardized placement into college-level courses, the multiple-measures approach allows more students to enroll in college-level courses during their first year. For students requiring additional support in college-level math, adopting a corequisite model can be beneficial, as it allows students to enroll in college-level math while simultaneously receiving the necessary academic support. Implementing such reforms may necessitate significant changes to developmental education programs, so colleges pursuing this strategy should engage faculty and staff early in the planning process, build trust, and shift institutional mindsets to support sustainable and successful reform efforts (Bickerstaff et al., 2022).

Math pathway reforms work best when students get clear advice about which math courses fit their academic goals. Standardized advising tools and stronger communication between math departments and other academic departments as well as advisors help guide students through their choice and support these reforms. For instance, Montgomery College held a series of meetings and training sessions for staff to ensure that everyone involved in student registration understood the changes in the math program. As a result, all new students were directed to consult an academic advisor before registering (Hamman et al., 2019). Community colleges implementing alternative math pathways should consider investing in onboarding and advising programs like these to empower students in choosing pathways that align with their academic and career goals.

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Technical Appendix

Data Description

The study used administrative data from the Maryland Higher Education Commission (MHEC). Our analysis focused on first-time-in-college (FTIC) students who entered one of Maryland's 16 community colleges between the 2014-15 and 2019-20 academic years. All students were tracked through summer 2021, providing at least two years of follow-up since their initial term of enrollment. Based on our analysis of college catalogs, three colleges not initially funded by the MMRI project adopted similar reforms to their developmental math programs during our study period. However, these colleges did not disclose details regarding the reform components they implemented. Consequently, we were unable to track which developmental courses on the statistics pathway were revised or designed, whether the structure of their developmental math courses was modified, or when these changes occurred. To prevent these three colleges from contaminating our estimation of MMRI effects, we excluded them from our analysis.

With this sample restriction, our final analysis focused on 89,300 students enrolled at the seven MMRI colleges and 59,868 students from six non-MMRI colleges, resulting in an analytic sample of 149,168 FTIC students, distributed relatively evenly across six entering cohorts (2014 to 2019). In the rare cases where a student has enrollment records at multiple community colleges within the state system, we assign their treatment status based on the first institution they attended. This approach is based on the assumption that developmental (either prerequisite or corequisite) and gateway math courses are typically among the first courses students take to fulfill degree requirements. It also helps mitigate potential self-selection bias, in case any students transferred from a non-MMRI college to an MMRI-participating college to take advantage of the expanded math pathways. However, we believe such cases are rare: only about 5% of students had course records at multiple colleges in our sample, and fewer than 1% were enrolled at more than one institution during the same term. Additionally, there were no statistically significant differences in co-enrollment rates between MMRI and non-MMRI colleges.

Methodology

Overall effects of MMRI. This study adopted a difference-in-differences (DID) approach to estimate the impacts of the MMRI on various student outcomes[11]. Changes in developmental math policy were expected to affect only students who entered MMRI colleges after the reform's implementation. Therefore, we compared changes in student outcomes at MMRI colleges before and after the reform, using non-MMRI colleges as the control group to account for any general time trends that could potentially influence all students within Maryland's higher education system. Specifically, our baseline model follows this specification:

$$y_{ijt} = \beta_0 + \beta_1(MMRI_j * Post_{jt}) + \beta_n X_i + \phi_t + \lambda_j + \mu_{ijt} \qquad (1)$$

Here, y_{ijt} is the outcome of student *i* of entering cohort *t* at college *j*. Since the primary objective of the Maryland Mathematics Reform Initiative was to broadly enhance student success in postsecondary mathematics and progression towards a postsecondary credential, our analyses focused on three sets of outcomes: (1) developmental math progression and completion; (2) gateway math enrollment and completion; and (3) major selection and persistence. For outcomes related to developmental math, we examined the proportion of students who completed the developmental math requirement by the end of their first year and the proportion of students who enrolled in a developmental-to-gateway math sequence with an aligned curriculum. For gateway math-related outcomes, we analyzed the proportion of students who enrolled in and completed gateway math by the end of their first year. Regarding major selection and persistence, we examined the likelihood of students declaring a STEM major during their first and second years, the total number of gateway or advanced college-level math courses completed by the end of their second year, and the likelihood of students persisting and transferring by the end of their second year.

In Equation 1, our main parameter of interest is β_1, the coefficient of the interaction term between the MMRI college indicator ($MMRI_j$) and an indicator for post-MMRI cohorts ($Post_{jt}$), which varies across colleges. The coefficient β_1 captures the overall effects of MMRI on the various outcomes described above. The vector X_i contains a set of student covariates, including gender, race, citizenship status, state and county residence status, military affiliation, whether the student was required to take developmental math, pre-college standardized test scores, high

[11] The technical appendix in the earlier MHEC policy brief (https://mhec.maryland.gov/publications/Documents/Research/PolicyReports/MHECPolicyBriefVol2.pdf) includes a visual explanation on the method of difference-in-differences.

school GPA, and enrollment status during the first term (fulltime vs. parttime). In this model, we also controlled for any general time trends through cohort fixed effects (ϕ_t) and any systematic differences in student outcomes across institutions through college fixed effects (λ_j). Robust standard errors were two-way clustered at college-, and cohort-level.

Heterogeneity-robust DID. As discussed in Goodman-Bacon (2021), two-way fixed-effects (TWFE) estimates derived from Equation 1 may yield biased results when the composition of the comparison group changes. Specifically, if the comparison group becomes a shifting mix of not-yet-adopters and non-adopters, the TWFE estimates may not be robust if treatment effects vary over time within groups. As described in the Background Section, several MMRI-participating colleges implemented the math pathway and developmental education structure reform components at different time points. To address potential biases arising from this context, we further examined the robustness of our results in cases involving varying effects between early and late adopters using heterogeneous-robust estimators developed by Callaway and Sant'Anna (2021). The event-study specification capturing group-time average treatment effects is expressed as follows:

$$y_{ijt} = \beta_0 + \sum_{t \neq -3}^{t} \gamma_i\left(Lag_{gt}\right) + \sum_{t \neq -3}^{t} \beta_i\left(Lead_{gt}\right) + \beta_n X_i + \phi_t + \lambda_j + \mu_{ijt} \quad (2)$$

In this model, Lag_{gt} and $Lead_{gt}$ are a series of binary indicator for group *g* for each treatment period relative to three academic years before treatment (*t = -3)*. A "group" is defined by the time when any MMRI reform component was first implemented.

Effects of different reform components. Since three out of the seven MMRI-participating colleges implemented structural reform to their developmental math programs on top of introducing alternative math pathways, the study is able to examine which reform components drove the overall reform effect, and for which student outcomes. To do this, we decomposed the MMRI effects using the following form:

$$y_{ijt} = \beta_0 + \beta_1\left(Pathway_j * PostP_{jt}\right) + \beta_2\left(Structure_j * PostS_{jt}\right) + \beta_n X_i + \phi_t + \lambda_j + \mu_{ijt} \quad (3)$$

In this model, $Pathway_j$ is a binary indicator for colleges that eventually implemented statistics pathways, and $PostP_{jt}$ is an indicator for post-statistics-pathway cohorts. Similarly, $Structure_j$ represents the indicator for the three colleges that eventually incorporated structural reforms as part of the MMRI, while $PostS_{jt}$ refers to post-structural-reform cohorts. The parameter β_1

captures the effects of introducing the statistics pathway on y_{ijt}, and the parameter β_2 reflects the effects of structural reforms, which included providing corequisite support and/or revising placement procedures with multiple measures.