A Multisite Study of High School Mathematics Curricula and the Impact of Taking a Developmental Mathematics Course in College

Michael Harwell *Danielle Dupuis* *Thomas R. Post*
Amanuel Medhanie *Brandon LeBeau*
University of Minnesota

Abstract

The relationship between high school mathematics curricula and the likelihood of students who enroll in a developmental (non-credit bearing) course in college taking additional mathematics courses was studied. The results showed that high school mathematics curriculum, years of high school mathematics completed, and ACT mathematics scores were related to developmental mathematics course-taking, but curriculum was not related to the subsequent mathematics course-taking of students who began college with developmental mathematics. The results have important implications for educational researchers and policymakers at the college and high school levels.

Key words: Developmental mathematics, college mathematics, high school mathematics curriculum

Students whose preparation for college mathematics is unsatisfactory continue to enroll in U.S. colleges in large numbers, prompting postsecondary institutions to invest significant resources to support mathematics learning (Bettinger & Long, 2009) (We define college as a four-year postsecondary institution offering a bachelor's degree). Among these resources are developmental mathematics courses, which are courses intended to lead to a student attaining the expected mathematics competency of entering college freshmen (Bahr, 2007). A 2003 report by the National Center for Education Statistics (NCES) stated that

16% of freshmen in four-year public institutions in the U.S. complete at least one developmental mathematics course, and 8% in private schools.

The prominence of developmental mathematics coursework in college has led to a rapidly growing research literature whose goals include a deeper understanding of its effectiveness and antecedents. This literature is frequently characterized as a debate between researchers and policy-makers who see developmental course-taking as enhancing college access, and those who see developmental courses as misguided because of the academic deficiencies of students enrolling in these courses (Attewell, Lavin, Domina, & Levey, 2006; Lavin & Weininger, 1998). However, there is agreement that students need to be better prepared for college mathematics (Augustine, 2007; NCES, 2006), thus reducing the need for developmental coursework and, correspondingly, the time, effort, and money invested in this activity by students and colleges.

Evidence of effectiveness has typically examined the impact of completing developmental mathematics courses on subsequent academic attainment especially college graduation. This literature is mixed, with some studies reporting that completing at least one developmental mathematics course reduces the likelihood that a student will stay in college, earn good grades, and graduate (Adelman, 2004; Deil-Amen & Rosenbaum, 2002; Martorell & McFarlin, 2010), whereas other studies report the opposite (Bettinger & Long, 2009; Lavin & Weininger, 1998). The search for antecedents has largely centered on using high school variables (e.g., GPA, percentile rank) as predictors of developmental mathematics course-taking (Attewell et al., 2006; Bettinger & Long, 2009; Hoyt & Sorensen, 2001).

Despite a burgeoning literature in developmental mathematics there are important gaps in our understanding of the antecedents of developmental coursework (Attewell et al., 2006; Tierney & Garcia, 2011). In particular, there is little literature examining the impact of high school mathematics curricula, an important component of the mathematics preparation of college-bound students, on the likelihood of students enrolling in a developmental mathematics course in college or their subsequent mathematics course-taking. There is also little evidence of the extent to which these patterns generalize across different kinds of postsecondary institutions.

Purpose of the Study

This study examined the relationship between the high school mathematics curriculum a student completed and the likelihood of students who enrolled in a developmental mathematics course in college taking additional mathematics courses for a sample of postsecondary institutions.

Developmental mathematics course-taking in college

How do students wind up in a developmental *mathematics course?*

The most common way to assess the mathematics preparation of newly enrolled students for mathematics involves placement tests. An NCES (2003) report noted that 57% to 61% of U.S. institutions used placement tests to identify students in need of developmental coursework, with some estimates as high as 90% of institutions (Education Week, 1994). Meristosis and Phipps (2000) suggested that institutions claiming not to use placement tests typically use the mathematics portions of the ACT or SAT tests as de facto placement tests. In practice, placement in a developmental mathematics course appears to rely on a combination of evidence including placement test(s) and information reflecting a student's preparation for college mathematics such as number of years of college-intending high school mathematics, GPA in high school mathematics courses, and ACT/SAT mathematics score (Attewell et al., 2006; Mzumara & Shermis, 2001).

What are the characteristics of students in developmental mathematics courses in college?

Students who complete developmental mathematics courses tend to have lower high school GPAs and ACT or SAT scores, are disproportionately non-White, older, female, and more likely to come from a low SES background compared to students not taking such courses (Adelman, 2004; Merisotis & Phipps, 2001; NCES, 2003, 2008). Still, it is important to emphasize that there are many exceptions to these patterns. For example, Attewell et al. (2006) used a sample from the National Educational Longitudinal Survey (NELS) and reported that 24% of the students in the highest SES quartile completed a developmental mathematics course, and Adelman (2004) reported that for the High School and Beyond and NELS datasets a total of 6.8% of the students in the top SES quintile completed at least one developmental mathematics course.

High school mathematics curricula

There are many reasons to believe that the high school mathematics curriculum a student completes plays a key role in their preparation for college mathematics, but there is disagreement over the ability of different curricula to prepare students for college mathematics (Schoenfeld, 2004). High school mathematics curricula in the U.S. can generally be categorized as those that are developed with funding from the National Science Foundation, commercially developed (CD) curricula, or the University of Chicago School Mathematics Project (UCSMP) curriculum.

National Science Foundation-funded curricula were developed with support from NSF in the early 1990's with the expectation that the development of new curricula would be guided by the *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics [NCTM], 1989). The current study included students who completed one of three NSF-funded high school curricula: *Contemporary Mathematics in Context* (CMIC or Core-Plus) (Coxford et al., 1998), *Interactive Mathematics Program* (IMP) (Fendel et al., 1998), and Mathematics: Modeling Our World (MMOW or ARISE) (Garfunkel, Godbold, & Pollack, 1998). These integrated curricula focus on multiple topics each year including algebra, geometry, probability, statistics and topics in discrete mathematics and are intended to be taught in ways that encourage conjecture, exploration, analysis and proof.

The most widely used mathematics curricula in U.S. high schools are non-integrated CD curricula, exemplified by widely-used textbook series such as Houghton-Mifflin, Glencoe-McGraw Hill, and Saxon. Characteristics of these curricula include partitioning the mathematics program beginning in 9th grade into separate years of algebra, geometry, a second year of algebra and for college intending students a senior year college algebra or pre-calculus course. Coursework typically pays significant attention to standard algorithms, repetition for skill development, and a heavy reliance on the teacher for student learning (Schoenfeld, 2004).

Another category is the University of Chicago School Mathematics Project (UCSMP). This curriculum was first developed in the early 1980s (Usiskin, 1986) and combines features of NSF-funded and CD curricula (Schoenfeld, 2004). The UCSMP curricula is perhaps best known through the mathematics textbooks that integrate algebra, geometry, algebra II, functions, statistics, pre-calculus, and discrete mathematics texts and simultaneously emphasize reading, problem-solving, everyday applications of mathematics, and technology.

Evidence of the Relationship between High School Mathematics Preparation and Developmental Mathematics Course-Taking in College

Studies examining high school antecedents of developmental mathematics course-taking have identified several indicators of students' mathematics preparation that predict developmental course-taking. Adelman (2004) reported that students taking developmental mathematics were more likely to have completed high school in an urban area and to be in the lower quintiles of a variable reflecting general learned abilities. Hagedorn et al. (1999) and Bettinger and Long (2009) found that ACT mathematics scores, high school GPA, high school mathematics GPA, and years of high school mathematics predicted the initial mathematics course a student enrolled in including developmental coursework.

The most pertinent finding to the current study is Harwell et al. (2009), who sampled students at a large university and reported that students completing an NSF-funded curriculum were somewhat more likely to take a developmental mathematics course in college than those completing a CD curriculum. The current study extends the work of Harwell et al. (2009) in two important ways. First, our results offer increased generalizability because data from 32 postsecondary institutions are analyzed. Second, we study college mathematics course-taking beyond the developmental course to learn if taking such a course reduces the likelihood of students completing additional mathematics courses. We also explore the data for descriptive evidence of students who successfully completed college level mathematics in high school yet took developmental mathematics in college, and students who took developmental mathematics in college but subsequently completed Calculus I, to provide insight into how students wind up in a developmental course and what happens afterwards.

Research Questions

Our research questions asked:

Is there is a relationship between the high school mathematics curriculum a student completed and the (1) likelihood students will complete a developmental mathematics course in college (2) subsequent college mathematics course-taking of students who completed a developmental mathematics course (3) extent to which results for (1) and (2) generalize across different kinds of postsecondary institutions.

Method

Research design

A retrospective cohort (quasi-experimental) cluster design was used in which archival data covering four years of high school and eight college semesters were obtained for students who enrolled in one of 32 post-secondary institutions (clusters/sites) in Fall 2002 or Fall 2003. Students completing the same high school mathematics curriculum were treated as members of the same curriculum cohort. We adopted several of the What Works Clearinghouse Standards (2008) to improve our inferences by taking into account pre-existing differences among cohorts using control variables in the data analyses.

Population and sample

The target population consisted of students enrolled in U.S. colleges who completed at least one mathematics course, whereas the sampled population was students enrolled in 32 colleges in the upper Midwest of the U.S. who completed at least one college mathematics course. The resulting sample of 32 colleges generated 13,188 students who completed at least three years of an NSF-funded, UCSMP, or CD curriculum. Three years was chosen as a cutoff for inclusion in the study because students taking the mathematics portion of the ACT or SAT test will generally be assumed to have completed at least three years (Carnegie units) of high school mathematics (ACT, 2009; College Board, 2010). Altogether 1, 526 of the 13, 188 students (11.6%) completed at least one developmental mathematics course in college.

Data collection, variables, and data analysis

Student records provided by the 32 institutions were used to extract high school information that included mathematics course titles for grades 9-12, ACT mathematics score, years of high school mathematics, and background information including ethnicity and sex. We also used student records to identify the high school mathematics curriculum a student completed (CD, NSF-funded, UCSMP). We combined the NSF-funded curricula (Core-Plus, MMOW, IMP) in our analyses for two reasons. First, each curriculum was constructed using a common set of standards (NCTM, 1989) and, thus, share a common set of goals and instructional practices designed to support mathematics learning. Second, multivariate analysis of variance found no differences between the NSF-funded curricula for high school (ACT mathematics scores, high school mathematics GPA, years of high school mathematics) or college (grades and difficulty level of mathematics courses) mathematics outcomes. We also coded a student's college major using a modified version of the categories appearing in an NCES (2005) report.

The documented impact of college characteristics on a range of student outcomes including mathematics (Braxton & McClendon, 2002; Ratcliff, Lubinescu, & Gaffney, 2001) prompted us to collect information on each institution's enrollment and educational profile, with the latter primarily a measure of selectivity measured using the ACT score corresponding to the 25th percentile of the freshmen class. This information was obtained from institution websites and the Carnegie Classification Undergraduate Profile website.

Dependent variables

The mathematics courses students completed were available for eight college semesters. To capture course-taking we created a four-point variable using information on the 32 institution websites:

Level 1: This level represents developmental courses that should have been completed in high school.

Level 2: This level includes courses that would be considered pre-Calculus mathematics and include College Algebra, Finite Mathematics, and coursework at a similar level.

Level 3: This would be the typical entry level for well-prepared high school students, who would start their college mathematics coursework with Calculus I.

Level 4: This level is beyond a first course in Calculus. Titles include Calculus II, differential equations, linear algebra, and multivariable Calculus.

The above levels overlap with those used in Teitlebaum's (2003) analysis of NELS data. The difficulty levels of 700 college mathematics courses completed by students at the 32 colleges were assigned by project staff after reviewing course descriptions. To answer our research questions we used the difficulty level variable to create three binary variables: took developmental mathematics (1 = yes, 0 = no); students who began with developmental mathematics and subsequently completed College Algebra/Pre-Calculus (1 = yes, 0 = 0); students who began with developmental mathematics subsequently completed Calculus I (1 = yes, 0 = no).

Data analysis

We fitted two-level (students within institutions) generalized linear models to cross-sectional (binary) data in our inferential analyses (Raudenbush & Bryk, 2002). Where appropriate we constructed between-institution models to predict variation in parameters.

Descriptive analyses

Developmental mathematics course-taking rates varied substantially across the sampled institutions. Sixteen institutions had approximately10% or less of their students in these courses. On the other hand, ten institutions had rates above 30%. The seventeen private colleges in our sample showed a binary pattern in which either few students or significant percentages of students completed a developmental mathematics course, whereas public institutions showed a consistent spread in these rates.

Table 1 reports summary statistics for curriculum cohort, sex, ethnicity, college major, and educational profile by developmental course status. Students in the NSF-funded cohort weremore likely to complete at least one developmental mathematics course (18.6%) as not; for the

CD and UCSMP cohorts these percentages were 10% and 8%, respectively. Within ethnic groups African American (36%) and Hispanic (26.1%) students were more likely to complete a developmental mathematics course as not, whereas few STEM students did (1.8%). Among

Table 1 Summary Statistics for Curriculum Cohort, Sex, Ethnicity, College Major, and Educational Profile by Developmental Course Status

		Developmental Status		Course	
		Yes		No	
		N	Row %	N	Row%
High School Mathematics Curriculum	NSF-funded	355	18.6	1559	81.4
	UCSMP	192	8.0	2213	92.0
	CD	979	10.0	7890	90.0
Sex	Female	1049	13.0	7032	87.0
	Male	656	10.0	5947	90.0
Ethnicity	Asian	187	17.0	916	83.0
	African American	148	36.0	262	64.0
	Hispanic	57	26.1	161	73.9
	Caucasian	1246	10.0	11244	90.0
College Major	STEM	37	1.8	2019	98.2
	Business	229	9.0	2293	91.0
	Humanities	772	15.7	4138	84.3
	Life Science	124	5.4	2158	94.6
	Other	63	11.6	478	88.4
Educational Profile	Full-time/More Selective	636	9.2	6287	90.8
	Full-Time/Selective	925	13.0	6174	87.0
	Full/Part-Time/Less Selective	152	22.2	530	77.8

Note: **Developmental course status Yes = completed at least one developmental mathematics course in college, N = sample size, NSF-funded = National Science Foundation-funded, UCSMP = University of Chicago School Mathematics Project, CD =**

commercially developed curriculum, STEM = Science, Technology, Engineering or Mathematics. For Educational Profile Full-time/More Selective = $\geq$ 80% students attend school on a full-time basis, average ACT score in upper one-fifth of all colleges, and low transfer-in rate of $\leq$ 20%; Full/Part-Time/Less Selective = mix of full-time and part-time students, mix of ACT scores, and high transfer-in rate of > 20%.
institutions those categorized as more selective, selective, and less selective showed rates of 9.2%, 13%, and 22.2%, respectively.

Table 2 shows the highest college mathematics course difficulty level attained by curriculum cohort and sex for students who started with a developmental mathematics course.

Table 2 Highest Difficulty Mathematics Course a Student Starting with a Developmental Mathematics Course by the Number of Developmental Mathematics Courses Taken

		Number of Developmental Mathematics Courses Taken							
		1			2			> 2	
	High Diff.	N	Row %	Col %	N	Row %	Col %	N	Row %
Overall	1	659	76.6	54.3	171	19.9	65.2	30	3.5
	2	479	83.6	39.4	83	14.5	31.4	11	1.9
	3	58	89.2	4.8	7	10.8	2.7	0	0.0
	4	18	85.7	1.5	3	14.3	.7	0	0.0
NSF-Funded	1	147	73.1	54.4	48	23.9	65.6	6	3.0
	2	112	81.8	41.5	20	14.6	27.4	5	3.6
	3	9	75.0	3.3	3	25.0	4.1	0	0.0
	4	2	50.0	.8	2	50.0	2.9	0	0.0
UCSMP	1	78	78.0	49.5	19	19.0	70.4	3	3.0
	2	71	86.6	45.1	8	9.8	29.6	3	3.6
	3	8	100.0	5.3	0	0.0	0.0	0	0.0
	4	1	100.0	.1	0	0.0	0.0	0	0.0

CD	1	434	77.6	55.2	104	18.6	63.4	21	3.8
	2	296	83.6	37.7	55	15.5	33.5	3	0.9
	3	41	91.1	5.2	4	8.9	2.4	0	0.0
	4	15	93.8	1.9	1	6.2	.7	0	0.0
Female	1	429	76.3	57.7	114	20.3	67.5	19	3.4
	2	274	82.5	36.9	50	15.1	30.0	8	2.4
	3	28	93.3	3.8	2	6.7	1.2	0	0.0
	4	12	80.0	1.6	3	20.0	1.3	0	0.0
Male	1	230	77.2	48.8	57	19.1	60.0	11	3.7
	2	205	85.1	43.5	33	13.7	34.7	3	1.2
	3	30	85.7	6.4	5	14.3	5.3	0	0.0
	4	6	100.0	1.3	0	0.0	0.0	0	0.0

Note: **High Diff. = Highest Difficulty (1 = developmental course, 4 = Calculus II or higher), NSF = National Science Foundation-funded curriculum, UCSMP = University of Chicago School Mathematics Project curriculum, CD = commercially developed curriculum. Maximum sample size =1,526.**

Overall, 54.3% of these students ended their mathematics course-taking at this difficulty level; of these students 19.9% took a second developmental mathematics course. Among the students in Table 2 who took one developmental course 45.7% subsequently completed a course of difficulty level 2 (College Algebra/Pre-Calculus) or a more difficult course. Among the NSF-funded, UCSMP, and CD cohorts the percentages of students who took one developmental course but finished their college mathematics course-taking at difficulty level 2 (College Algebra/Pre-Calculus) were 41.5%, 45.1%, and 37.7% and at difficulty level 3 (Calculus I) were 3.3%, 5.3%, and 5.2%, respectively.

Inferential Analyses

College mathematics course difficulties

We initially fitted a multilevel model to the binary (cross-sectional) data indicating whether a student completed a developmental mathematics course in college (1 = yes, 0 =

no). The discontinuous and multimodal nature of college enrollments led us to trichotomize this variable into high, medium, and low enrollments using the data and to dummy-code this variable.

The fixed effects results are presented in Table 3 and show that students completing an NSF-funded curriculum were more likely to take a developmental mathematics course in college than the CD cohort ($\hat{\beta}$ = .278). Exponentiating this result (Raudenbush & Bryk, 2002) shows that students in the NSF-funded cohort were about 1.32 times more likely to take a developmental mathematics course as not, compared to students in the CD cohort. Equivalently, the model-implied probability a student who completed an NSF-funded curriculum will take a developmental mathematics course in college is .57, meaning that for the CD cohort this probability is .43. There were no differences between the UCSMP and CD cohorts in the likelihood of taking a developmental mathematics course. The college major variable had the largest effect, with Humanities majors about 9.6 times more likely to take a developmental mathematics course as not compared to STEM majors. The ACT 25th percentile mathematics score of the freshman class was a significant predictor of intercepts at the institution level,
indicating that students in institutions with higher scores were less likely to take a developmental mathematics course.

A second binary difficulty variable reflected whether students who began with adevelopmental mathematics course subsequently took College Algebra/Pre-Calculus. These results (not reported) showed that among students who began college with a developmental mathematics course, high school mathematics curriculum was not related to taking College Algebra/Pre-Calculus. Analysis of a third binary

Table 3 Fixed Effect Results for the Likelihood of Completing a Developmental Mathematics Course in College (1 = yes, 0 = no)

Between Student Model:	β	SE (β)	t-value
Intercept	-5.205	1.596	-3.261
ACT Mathematics	-0.311	0.015	-20.597
UCSMP	-0.110	0.131	-0.846
NSF	0.278	0.112	2.470
Business	1.231	0.258	4.776
Humanities	2.262	0.249	9.089
Life Sciences	1.153	0.271	4.255
Other	1.562	0.319	4.901
Sex	0.310	0.098	3.149
African American	0.410	0.194	2.109
Asian	-0.154	0.161	-0.957
Hispanic	0.335	0.277	1.210
Years High School Mathematics	-0.629	0.075	-8.342
Between Institution Model:			
Full-time/Selective	-2.818	2.356	-1.196
Full/Part-time/Less Selective	-4.340	3.634	-1.194
ACT 25th percentile	-1.393	0.487	-2.860
Small Enrollment	-2.985	1.480	-2.017
Medium Enrollment	-0.739	1.349	-0.548

Note. **Significant results in bold based on $\alpha' = 1-(1-\alpha)^{1/k}$ = .009951 where α = .15 is the unadjusted Type I error rate, k = number of statistical tests = 17, and α' is the adjusted error rate. Years high school math = 3,4,5; UCSMP 1 = yes 0 = no, NSF-funded 1 = yes 0 = no so CD served as the reference group; Sex 1 = male, 0 =**

female; African American 1 = yes, 0 = no; Asian 1 = yes, 0 = no; Hispanic 1 = yes, 0 = no so White students served as the reference group; Business 1 = yes, 0 = no, Humanities 1 = yes, 0 = no, Life Sciences 1= yes, 0 = no, Other 1 = yes 0 = no so STEM served as the reference group; Full-time/Selective 1 = yes, 0 = no, Full/Part-time/Less Selective 1 = yes, 0 = no so Full-time/More Selective served as the reference group; Small Enrollment 1 = < 2110, 0 = > 2110, Medium Enrollment 1 = 2,110 to 3,548, 0 = > 3,548 so Large Enrollment (> 3,548) served as the reference group. Student sample size = 10, 345.

difficulty variable (whether students who began with developmental mathematics subsequently took Calculus I) (not reported) showed that only the college major variable was significant.

Comparing student subgroups who took developmental mathematics in college

We examined two student subgroups in our data with unexpected educational trajectories. Seventy-three students completed five years of high school mathematics (the fifth year is typically Calculus I) yet started college mathematics with a developmental course. The percentage of these students in the CD, NSF-funded, and UCSMP cohorts were 2%, 3.5%, and 1.8%, respectively. Students who completed five years of high school mathematics yet took a developmental course had on average weaker mathematics preparation than students who completed five years of high school mathematics but did not take a developmental course, as suggested by average ACT mathematics scores (21.2 versus 27, respectively). Approximately 58% of the students who completed five years and took a developmental course subsequently completed College Algebra/Pre-Calculus or a more difficult course.

We also found that 77 students began their college mathematics coursework with a developmental course but eventually completed Calculus I. The percentage of these students for the CD, NSF-funded, and UCSMP cohorts were 1.4%, 0.7%, and 2.7%, respectively.

DISCUSSION

Our results agree with those of Harwell et al. (2009) that students completing an NSF-funded curriculum were more likely to begin college with a developmental mathematics course. One explanation of this result is that NSF-funded curricula simply do not prepare students as well as other curricula, but another explanation is a lack of alignment of the NSF-funded curricula with college mathematics placement tests when compared with the CD and UCSMP curricula (Norman, 2008). These results, as well as our descriptive finding that students who completed five years of high school mathematics (including Calculus I) wound up in a developmental mathematics course, highlights the need for a better understanding of how students are placed in these courses.

Our key finding, which substantially extends the results of Harwell et al. (2009), is that among the approximately 46% of the students who began college with a developmental mathematics course and subsequently completed at least one non-developmental mathematics course, the NSF-funded cohort was just as likely to complete College Algebra or Calculus I as the other cohorts. These results suggest that taking a developmental mathematics course does not permanently limit a student's upwards mathematical mobility.

Implications

For colleges, these results suggest that developmental mathematics coursework can provide a path to success in college mathematics as many of these students go on to take additional courses. For high schools, our results suggest that mathematics curriculum is related to the difficulty level of the first college mathematics class a student enrolls in but is unrelated to subsequent mathematics course-taking. The latter is important because we think where a student finishes their college mathematics course-taking is more important than where they began. Collectively, we think these results suggest it is premature to abandon or adopt any high school mathematics curricula on the basis that they differentially prepare students for college mathematics, including developmental mathematics course-taking.

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