Abstract Title Page

Title:

A Multi-Site Study of the Relationship Between High School Mathematics Curricula and Developmental Mathematics Course-Taking and Achievement in College

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Background/context:

Students whose preparation for college mathematics is unsatisfactory continue to enroll in four year post-secondary institutions, prompting colleges to invest significant resources to support mathematics learning (Bettinger & Long, 2009). Among these resources are developmental mathematics courses (courses that generally do not carry college credit and normally would have been completed in high school) that are intended to prepare students to succeed in subsequent college mathematics coursework. Currently about 25% of all college freshmen complete at least one developmental mathematics course (National Center for Education Statistics [NCES], 2003a), with estimates as high as 40% for traditional undergraduates (Attewell, Lavin, Domina, & Levey, 2006).

Despite its scale there is significant concern over the role of developmental mathematics coursework in college for at least two reasons. First, evidence of the impact of successfully completing developmental mathematics courses on subsequent academic attainment is mixed (Bahr, 2007; Bettinger & Long, 2009; Merisotis & Phipps, 2000). Second, there is mixed evidence of the cost effectiveness of developmental courses (Attewell et al., 2006; Bahr, 2007; Hoyt & Sorenson, 1999). These concerns have led some U.S. states to remove developmental courses from state sponsored colleges and to direct students in need of developmental coursework to community colleges (i.e., two year institutions) (Bettinger & Long, 2004).

Moreover, there are important gaps in our understanding of the antecedents and effectiveness of developmental coursework (Attewell et al., 2006). For example, our current understanding of the high school mathematics preparation of students who complete developmental mathematics coursework is limited to using student outcomes in high school (e.g., GPA, percentile rank) as predictors of developmental courses in college (Bettinger & Long, 2009). No studies have examined the impact of high school mathematics curricula, an important component of the mathematics preparation of college bound students, on the likelihood of students completing a development mathematics course in college. Also, there is little information on subsequent college mathematics coursework completed by these students or their achievement in these courses. Our study adds to this literature.
Purpose/objective/research question/focus of study:

This study examines the impact of completing a commercially developed (CD), NSF-funded, or University of Chicago School Mathematics Project (UCSMP) mathematics curricula in high school on the likelihood of students completing a developmental mathematics course in college and on subsequent college mathematics course-taking and achievement. A few studies have found effects suggesting one curriculum or another leads to students starting with and continuing more (or less) difficult college mathematics classes (Harwell et al., 2009; Hill & Parker, 2006) and earning higher (or lower) college math grades (Harwell et al., 2009; Schoen & Hirsch, 2003). However, none have focused on the relationship between high school mathematics curricula and developmental mathematics in college or subsequent patterns of mathematics course-taking and achievement. The proposed study has important implications for educational researchers, policymakers at the college and high school levels, teachers, parents, and students. In particular, the results will increase our understanding of the antecedents associated with 25% of all freshmen taking at least one developmental mathematics course, and the impact of successfully completing a developmental course on subsequent mathematics course-taking and achievement. This information will inform policies and practices that support student mathematics learning.

We pose the following questions: (1) What is the impact of high school mathematics curricula on the likelihood students will complete a developmental mathematics course in college and on subsequent mathematics course-taking and achievement? (2) Can these relationships be generalized across colleges varying in size, educational profile, and selectivity?

Setting:

The data come from archival datasets reflecting student background variables, high school mathematics course-taking and grades, and college mathematics course-taking and grades across eight semesters.

Population/Participants/Subjects:

The target population consists of colleges in the U.S. whereas the sampled population consists of colleges in the upper Midwest of the U.S. that vary in several ways (e.g., educational profile). The sample(s) consist of approximately 10,000 students who earned a degree in one of 35 four year colleges (defined as a post-secondary institution offering a bachelor’s degree) in the upper Midwest, completed at least three levels (years) of high school mathematics in a CD, NSF-funded, or UCSMP curriculum, and who completed at least one non-developmental college mathematics course for credit. Participation was limited to students completing at least three years (Carnegie units) of high school mathematics, as reflected in the mathematics portions of the ACT and SAT tests (ACT, 2009; College Board, 2009). Altogether 2,833 (of the 10,000) sampled students completed a developmental mathematics course in college. These data have been collected and are available for analysis.

Intervention/Program/Practice:

There are three general categories of high school mathematics curricula in the U.S. The most widely used mathematics curricula in the nation’s approximately 21,000 high schools are CD curricula that
stress traditional algorithms and procedures (Education Market Research, 2006). These curricula are typically organized as separate years of algebra, geometry, and advanced algebra, and within each year the texts are divided into chapters which focus on algorithmic development with problem solving that concentrates on solving word problems. Student communication is not a central focus of these texts and mathematical content is, in general, explained by the teacher. National Science Foundation-funded curricula were designed to be aligned with the National Council of Teachers of Mathematics’ Curriculum and Evaluation Standards for School Mathematics (1989) and include Contemporary Mathematics in Context (CMIC or Core-Plus, Coxford et al., 1998), Interactive Mathematics Program (IMP, Fendel, Resek, Alper, & Fraser, 1998) and Mathematics: Modeling Our World (MMOW or ARISE, Garfunkel, Godbold, & Pollack, 1998). A theme of these curricula is their focus on algebra, geometry, probability, statistics and topics in discrete mathematics, de-emphasis of algorithmic manipulation, and an emphasis on the role of students as active participants in a learning process that involves problem-solving, small group work, and connections to the world outside the classroom. A third category of curriculum is represented by the UCSMP curricula which are a hybrid of CD and NSF-funded curricula (Schoenfeld, 2004).

**Research Design:**

A retrospective cohort cluster design involving archival data for students who enrolled at (and graduated from) one of 35 colleges (clusters/sites) will be used. Students completing the same high school mathematics curriculum were treated as members of the same cohort. All students enrolled in college in the Fall of 2001 or 2002.

**Data Collection and Analysis:**

Data were obtained from college records and included the number of years of high school mathematics a student completed and titles of their high school mathematics courses, which were used to identify a student’s high school mathematics curriculum (Details of this process appear in Harwell et al., 2009). College records also yielded the titles and grades of student’s mathematics coursework across eight college semesters and student background variables. We also collected information about the characteristics of sampled colleges using institution websites, a State Department of Education website, and the Carnegie Foundation website [http://classifications.carnegiefoundation.org/lookup_listings/standard.php?key=783](http://classifications.carnegiefoundation.org/lookup_listings/standard.php?key=783). College-level variables included size (captured by enrollment = number of full-time + part-time students), selectivity (ACT mathematics score of the freshmen class corresponding to the 25th percentile as reported on institution websites), percentages of African American students and STEM majors, and educational profile (full-time = ≥ 80% students attend school on a full-time basis, more selective = average ACT score in upper one-fifth of all colleges, selective = average ACT score in middle two-fifths of all colleges), transfer rate (high transfer-in = ≥ 20%, low transfer-in rate = < 20%).

We also created a variable reflecting the difficulty level (1-4) of the college mathematics courses students completed to capture course-taking after examining mathematics course descriptions at the sampled colleges: Level 1 represents developmental courses that should have been completed at the high school level; Level 2 includes courses that would be considered pre-Calculus mathematics and include college algebra, finite mathematics, and coursework at a similar level; Level 3 reflects typical entry level
courses for well-prepared high school students who would start their college mathematics coursework with Calculus I; Level 4 represented the difficulty of courses beyond a first course in Calculus.

Our dependent variables are (1) completed a developmental mathematics course in college 1 = yes (difficulty level = 1), 0 = no; (2) difficulty levels of mathematics courses taken for credit across eight semesters; (3) difficulty levels of mathematics courses taken for credit across eight semesters by students who did not initially complete a developmental mathematics course; (4) grades corresponding to dependent variables (1) through (3). Each dependent variable will be analyzed separately.

We will use multilevel modeling in our inferential analyses (Raudenbush & Bryk, 2002). Some analyses will use cross-sectional data (e.g., likelihood a student completes a developmental mathematics course in college) and others longitudinal data (e.g., grades of college mathematics courses completed for credit over eight semesters). Similarly, some analyses will use standard (normal theory) multilevel models while others will use generalized linear models. The most complex modeling will involve three levels (repeated measures within students, students within colleges). For example, for longitudinal grade analyses we will fit a within-student model of the form

$$Y_{pik} = \pi_{0ik} + \pi_{1ik} \text{Semester}_{pik} + \pi_{2ik} \text{Difficulty}_{pik} + e_{pik}$$  \hspace{1cm} (1)$$

where $Y_{pik}$ is the mathematics grade of the ith ($i = 1, 2, ..., N$) student in the pth ($p = 1, 2, ..., P$) mathematics course completed at the kth ($k = 1, 2, ..., K$) college, $\text{Semester}_{pik}$ is a covariate indicating the semester a mathematics course was completed (first, second, etc.), $\text{Difficulty}_{pik}$ is a covariate with a Likert-type scale capturing course-taking patterns, $\pi_{1ik}$ is the slope of the ith student reflecting the linear trajectory of grades over Semester adjusted for Difficulty, $\pi_{2ik}$ is the slope of the ith student reflecting the impact of Difficulty on grades over mathematics courses completed, and $e_{pik}$ is within-student error.

Where appropriate we will construct between-student models to predict variation in these parameters of the form

$$\pi_{0ik} = \beta_{00k} + \sum \beta_{0k} X_{ik} + r_{0ik}$$  \hspace{1cm} (2)$$

$$\pi_{1ik} = \beta_{10k} + \sum \beta_{1k} X_{ik} + r_{1ik}$$  \hspace{1cm} (3)$$

$$\pi_{2ik} = \beta_{20k} + \sum \beta_{2k} X_{ik} + r_{2ik}$$  \hspace{1cm} (4)$$

where $\beta_{0k}$ is a slope capturing the impact of student-level covariates $X_{ik}$ (e.g., high school mathematics curriculum, ACT mathematics score, high school mathematics GPA, college major coded following NCES (2003b)) on intercepts, $r_{0ik}$ is an error term, and $\beta_{1k}$ is a slope capturing the impact of $X_{pik}$ on growth trajectories (slopes). Similarly, where appropriate models (not presented) capturing between-college (site) variation in intercepts in equations (2 - 4) will also be fitted with college level covariates.
Hierarchical generalized linear models using Difficulty as the outcome will be fitted in the same way except that the within-student model will not contain the covariate Difficulty. The key covariate in these models is the high school mathematics curriculum a student completed. We will follow the suggestions of Bliese and Ployhart (2002) to identify the best fitting model, and to control for compounding of Type I error rates we will use an adjusted error rate attributed to Sidak (1967). Multilevel analyses will be performed with the R 2.10.1 lme4 package (The R Foundation for Statistical Computing, 2009).

In high schools offering both CD and NSF-funded curricula more mathematically able students tend to be steered into CD curricula and less able student into NSF-funded curricula (Harwell et al, 2009). A selection bias of this nature would be expected to favor students who completed a CD curriculum as they move into college mathematics coursework, and disadvantage students who completed a NSF-funded curriculum. Another source of selection bias is the first college mathematics course recommended to students, which appears to depend heavily on a student’s score on college mathematics placement tests (Norman, 2008). Other things being equal, we expect students whose high school mathematics curriculum is aligned with items on a college mathematics placement test to perform well, which would be expected to favor students who completed a CD curriculum.

To respond to the possibility of selection biases linked to quasi-experimental designs (What Works Clearinghouse, 2008) we will (i) include statistical control variables in the multilevel analyses (e.g., high school mathematics GPA, ACT mathematics score) to take into account pre-existing differences in mathematics proficiency (ii) perform additional multilevel analyses to assess the sensitivity of our findings to such bias. For example, sensitivity analyses for the grade data will condition the analyses of student achievement on the difficulty level of a student’s first college mathematics course. Specifically, we will examine mathematics achievement by refitting our multilevel models to the grade data for students who began their college mathematics course-taking with a course of similar difficulty, for example, college algebra. This strategy ensures that grades/grade trajectories will be examined for students who began their college mathematics with a course of the same difficulty level and help to control for the effects of how or why students wound up in a particular high school mathematics curriculum and their initial college mathematics course.

Findings/Results:

Preliminary analyses suggest that the NSF-funded cohort is more likely to enroll in a developmental mathematics course in college and to exhibit a different pattern of mathematics course-taking.

Conclusions:

The results of the proposed study will increase our understanding of the antecedents associated with 25% of all freshmen completing at least one developmental mathematics course, and the impact of successfully completing a developmental course on subsequent mathematics course-taking and achievement. This information will inform policies and practices that support student mathematics learning.
Appendix A. References


Norman, K. (2008). *High school mathematics curriculum and the process and accuracy of initial mathematics placement for students who are admitted into one of the STEM programs at a research institution.* Unpublished dissertation, University of Minnesota Twin Cities.


