Abstract Title Page

Title:

A Multi-Institutional Study of the Impact of High School Mathematics Curricula on College Mathematics Achievement and Course-Taking

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Background/context:

Understanding the impact of high school mathematics curricula on college mathematics achievement and course-taking is important for three related reasons. First, it is important to establish an empirical research base characterizing the efficacy of these curricula for college-bound students (Mathematical Sciences Education Board, 2004; National Center for Education Statistics [NCES], 2006; 2008a, 2008b; National Research Council, 2002). Research examining the impact of high school mathematics curricula on students' college mathematics performance has typically focused on National Science Foundation (NSF)-funded curricula, in large part in response to intense criticism of these curricula as detailed in Schoenfeld (2004). The essence of the criticism for college bound students is that NSF-funded curricula do a poor job of preparing these students to succeed in calculus and other college mathematics courses (Klein, 2000; Wu, 1997). This study contributes to this research base by examining the impact of these curricula on the grades students earn in, and the difficulty level of, their college mathematics courses.

Second, there is widespread agreement on the need to better understand the mathematics preparation of students who complete undergraduate degrees in science, technology, engineering, and mathematics (STEM) disciplines, who are crucial in helping to meet the country's future technological needs (Committee on Prospering in the Global Economy of the 21st Century, 2007; Congressional Research Service, 2006, 2008). This study adds to our understanding of the preparation and performance of students who complete STEM college degrees.

Third, it is important to examine the ability of high school mathematics curricula to prepare an increasingly diverse group of students for college mathematics for a range of post-secondary institutions varying in size, mission, and student selectivity. This study provides importance evidence about generalizability across various student subgroups and post-secondary institutions.

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 preparation of students for college mathematics using the grades earned in college mathematics courses and the difficulty of those courses for a sample of post-secondary institutions. To better understand the impact of completing a particular high school mathematics curriculum on college mathematics achievement and course-taking for a range of post-secondary institutions, and for a range of students including those who completed a STEM major, we posed the following questions: (1) What is the nature and magnitude of the impact of high school mathematics curricula on student achievement in, and difficulty level of, college mathematics courses, and can these relationships be generalized across post-secondary institutions varying in size, mission, and selectivity? (2) Does this relationship change across institutions for diverse groups of students (e.g., African-American, White) including those who complete a STEM college degree and if so how?

Available literature of the impact of high school mathematics curricula on college mathematics achievement and course-taking is sparse and mixed. 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) and earning higher (or lower) college math grades (Hill & Parker, 2006; Schoen & Hirsch, 2003).

The current study has important implications for educational researchers, policymakers at the high school and college levels, teachers, parents, and students. The results will assist high schools seeking to identify curricula that best serve their college-bound students (including those interested in STEM majors), and colleges seeking to understand the antecedents associated with approximately 25% of all freshmen taking at least one remedial mathematics course (i.e., a course that should have been completed in high school) (NCES, 2003a). This study contributes to this research base by examining the impact of high school mathematics curricula on the grades students earn in, and the difficulty level of, college mathematics courses as a function of the high school mathematics curriculum they completed for a range of post-secondary institutions.

Setting:

The data come from archival datasets provided by 35 post-secondary institutions located in the upper midwest of the U.S. and reflect high school and college mathematics grades and course-taking patterns.

Population/Participants/Subjects:

The samples consist of approximately 16,000 students who earned a college degree in one of 35 four year post-secondary institutions in the upper midwest of the U.S., completed at least three levels (years) of high school mathematics in a CD, NSF-funded, or UCSMP curriculum, and who completed at least one college mathematics course. Participation was limited to students completing at least three years

(Carnegie units) of high school mathematics, which helped to ensure that students had sufficient exposure to a curriculum to allow its effects to appear. Approximately one-third of the students graduated from a high school in which two curricula were offered: CD or NSF-funded, or UCSMP or NSF-funded. These data have been collected and are available for analysis.

Intervention/Program/Practice:

There are three general categories of high school mathematics curricula. The most widely used mathematics curricula in the nation's approximately 21,000 high schools are commercially developed or traditional curricula that stress traditional algorithms and procedures. National Science Foundation-funded curricula represent those funded through a solicitation of proposals through the National Science Foundation in the early 1990's (RFP NSF 91-100) that were designed to be aligned with the National Council of Teachers of Mathematics' Curriculum and Evaluation Standards for School Mathematics (1989). The mathematics curricula funded by NSF included: Contemporary Mathematics in Context (CMIC or Core-Plus), Interactive Mathematics Program (IMP), and Mathematics: Modeling Our World (MMOW or ARISE). 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 (quasi-experimental) cluster design was used in which archival college mathematics grade and course-taking (difficulty) data were obtained across eight semesters for students who enrolled at (and graduated from) one of 35 post-secondary institutions (clusters). Students completing the same high school mathematics curriculum were treated as members of the same cohort.

Data Collection and Analysis:

We are using three-level multilevel modeling (Raudenbush & Bryk, 2002) with repeated measures nested within students and students nested within post-secondary institution. For the grade data we are fitting a within-student model of the form

$$Y_{p_{ik}} = \pi_{0_{ik}} + \pi_{1_{ik}} \text{Semester}_{p_{ik}} + \pi_{2_{ik}} \text{Difficulty}_{p_{ik}} + e_{p_{ik}} \qquad (1)$$

where $Y_{p_{ik}}$ is the mathematics grade of the ith (i = 1, 2, ...,N) student in the pth (p = 1,2,...,P) college mathematics course completed at the kth (k = 1,2,...,J) post-secondary institution, $\text{Semester}_{p_{ik}}$ is a covariate indicating the semester a mathematics course was completed (first, second, etc.) which was recoded as p -1 so that the intercept of the ith student $\pi_{0_{ik}}$ at $\text{Semester}_{p_{ik}} = 0$ reflects the first mathematics grade earned, $\text{Difficulty}_{p_{ik}}$ is a covariate with a Likert-type scale capturing course-taking patterns, $\pi_{1_{ik}}$ is the slope of the ith student reflecting the linear trajectory of grades over Semester adjusted for Difficulty, $\pi_{2_{ik}}$ is the slope of the ith student reflecting the impact of Difficulty on grades over mathematics courses completed, and $e_{p_{ik}}$ is within-student error.

We are constructing between-student models to predict variation in these parameters of the form

$$\pi_{0_{ik}} = \beta_{00_k} + \sum \beta_{0_k} X_{ik} + r_{0_{ik}} \quad (2)$$

$$\pi_{1_{ik}} = \beta_{10_k} + \sum \beta_{1_k} X_{ik} + r_{1_{ik}} \quad (3)$$

$$\pi_{2_{ik}} = \beta_{20_k} + \sum \beta_{2_k} X_{ik} + r_{2_{ik}} \quad (4)$$

where β_{0_k} is a slope capturing the impact of student-level covariates X_{ik} (i.e., cohort/high school mathematics curriculum, ACT mathematics score, high school mathematics GPA, high school percentile rank, sex, ethnicity, and college major coded following NCES (2003b)) on intercepts, $r_{0_{ik}}$ is an error term, and β_{1_k} is a slope capturing the impact of $X_{p_{ik}}$ on growth trajectories (slopes). Models (not presented) capturing between-institution variation in intercepts in equations (2 - 4) will also be fitted with various covariates (e.g., average ACT score of entering freshmen, number of students enrolled, primary educational mission captured with a variable reflecting an institution's Basic Classification in the Carnegie Foundation for the Advancement of Teaching). 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.

Credible examinations of the impact of high school mathematics curricula on college mathematics require that we take into account selection bias in the high school curriculum a student enrolled in. In high schools offering two curricula more mathematically able students tend to be steered into CD curricula and less able student into NSF-funded curricula (Harwell et al, 2009). Anecdotally, this appears to be the result of some high schools treating the NSF-funded curricula as a remedial alternative for less proficient students, and to involve teachers, counselors, principals and in some cases parents in the curriculum placement decision. A selection bias of this nature would be expected to favor students who completed a CD or UCSMP curriculum as they move into college mathematics coursework, and at least initially disadvantage students who completed a NSF-funded curriculum.

Another source of selection bias is the first college mathematics course recommended to students. Other things being equal, we expect students who completed a particular mathematics curriculum in high school to perform well on a college mathematics placement test whose content and structure tend to match their high school mathematics curriculum (O'Neill, 2002). A selection bias of this nature would be expected to favor students who completed a CD or UCSMP 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 a series of additional multilevel analyses to assess the sensitivity of our findings to such bias for the grade data. We are specifically interested in learning if multilevel findings capturing the effect of curriculum cohort are sensitive to a selection bias of this nature.

Sensitivity analyses for the grade data will condition the longitudinal analyses of student achievement on the difficulty level of a student's first college mathematics course. Specifically, we will examine longitudinal 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 grade trajectories and initial mathematics grade 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. This strategy is consistent with Pedhazur and Schmelkin's (1991, pp. 213-215) elimination strategy.

A final sensitivity analysis will refit the grade and difficulty multilevel models using a subsample of students known to have graduated from a high school offering a single mathematics curriculum (approximately 11,000 students), and compare these findings to those based on the full sample. This will allow the effects of cross-curriculum contamination (within high schools offering two curricula) on college mathematics to be assessed. To control for compounding of Type I error rates we will use the Benjamin-Hochberg method (What Works Clearing House, 2008).

Findings/Results:

Preliminary results indicate that for some post-secondary institutions (i) initial college mathematics course grade and course difficulty vary across students and that high school mathematics curriculum is a significant predictor of difficulty (but not grade) of some college mathematics courses (including calculus I) (ii) the trajectory of grades and difficulty levels of college mathematics courses across semesters vary across students, that high school mathematics curriculum is not a significant predictor of these trajectories, but whether a student completed a STEM major is. There is also preliminary evidence of variation in trajectories across student ethnicity.

Conclusions:

Our findings will have important implications for educational researchers, policymakers at the high school and college levels, teachers, parents, and students. First, our results will provide evidence of the ability of high school mathematics curricula to prepare students for college mathematics, including calculus I, for a range of post-secondary institutions. Second, our results will deepen our understanding of the mathematics preparation of students who completed a STEM major at post-secondary institutions varying in size, institutional mission, and student selectivity. Third, the results will provide a more comprehensive picture of the ability of high school mathematics curricula to prepare an increasingly diverse group of students for college mathematics.

Appendix A. References

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