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Improving Mathematics and Science Education

A Longitudinal Investigation of the
Relationship Between Reform-Oriented
Instruction and Student Achievement

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Summary

Background and Purpose

Reform-oriented teaching is a collection of instructional practices that was a prominent feature of reforms in mathematics and science education beginning in the 1990s. Such practices, which are consistent with the National Science Education Standards (National Research Council, 1996), stressed instruction that engages students as active participants in their own learning and emphasizes the development of complex cognitive skills and processes. Despite large investments in the promotion of reform-oriented curricula and instruction, the evidence supporting the effectiveness of these practices in raising mathematics and science achievement is relatively weak.

This monograph presents the findings of a multiyear study of the effectiveness of reform-oriented mathematics and science instruction. It builds on an earlier RAND study, called the Mosaic project, which found “a weak but positive relationship” between reform practices and student achievement (see Klein, Hamilton, McCaffrey, Stecher, Robyn, and Burroughs, 2000; Hamilton, McCaffrey, Stecher, Klein, Robyn, and Bugliari, 2003). The present study, called Mosaic II, extends this earlier research in two important ways. First, it incorporates more-diverse indicators of student exposure to reform-oriented practices, including innovative, vignette-based measures. Second, it follows students for three years to measure the relationship after longer exposure. Similar to the earlier research, this study uses multiple measures of

achievement, including open-ended assessments, to determine whether the relationship is sensitive to the manner in which achievement is measured.

Mosaic II was designed to answer two major research questions:

- Is the use of reform-oriented instructional practices in mathematics and science associated with higher student achievement?
- Is the relationship between reform-oriented practices and achievement sensitive to the aspects of achievement that are measured?

Methods

Mosaic II is an observational study, relying on naturally occurring variation in teaching practices as the basis for uncovering relationships between reform-oriented practice and student outcomes. That is, the design assumes that there is substantial variation in teaching practices among teachers within a school, even though teachers may have been exposed to the same training. To find a sample of teachers that encompassed a range of different instructional approaches, including reform-oriented instruction, we selected three districts that had recently concluded their participation in the Local Systemic Change program, a five-year National Science Foundation initiative to promote reform-oriented, systemic reform of mathematics and science education. Within these three districts, we selected five cohorts of students and followed each for three years beginning in the 2001–2002 school year. The cohorts varied in student age and academic subject being studied, with mathematics examined in three cohorts (grades 3 through 5; 6 through 8; and 7 through 9) and science examined in the remaining two cohorts (grades 3 through 5 and 6 through 8). All the teachers who were responsible for teaching the targeted subject (mathematics or science) to students in the five cohorts were included in the research in the year or years they taught the subject to the students.

For all five cohorts, achievement was measured using the mathematics or science component of the Stanford Achievement Test Series, Ninth Edition (SAT-9), published by Harcourt Assessment. For most

analyses, only the total score was available. However, for one mathematics cohort, we also obtained the Problem-Solving and Mathematical Procedures subscale scores. In addition, in two science cohorts and one mathematics cohort, we administered the open-ended version of the SAT-9 so that we could compare students' performance on open-ended and multiple-choice measures.

A key feature of the Mosaic II study is the use of multiple measures to determine the extent to which reform-oriented teaching practices were being used in the classroom. Each year, all participating teachers completed a survey, filled out classroom logs, and responded to a set of vignette-based questions about instructional practices. In selected years, we supplemented the main data-collection procedures with classroom observations and interviews conducted with a smaller subset of teachers. We used teacher responses to the surveys, logs, and vignettes, and observers' ratings of classrooms to derive a number of measures of instructional practices, teacher background, curriculum coverage, and classroom context.

One of the innovative features of this study is the use of vignette-based measures of instructional practice. *Vignettes* are contextualized descriptions of hypothetical classroom situations that can be used to elicit information about potential teaching behaviors. In this study, vignette-based items were used to try to ascertain teachers' tendencies to use reform-oriented instructional practices. We developed two vignettes for each subject-grade combination. Each vignette contained four instructional problems that provided teachers with hypothetical classroom events at different points within the given mathematics or science unit.

After each instructional problem, teachers were presented with a list of options that reflected a range of teaching actions, from behaviors that were not associated with reform pedagogy to teacher behaviors that were consistent with reform-oriented teaching. Teachers were asked to rate their likelihood of engaging in each option, using a four-point scale from "very unlikely" to "very likely," or, for questions of emphasis, from "no emphasis" to "great emphasis."

We derived two measures from the vignettes. The first measure, Reform-High, reflects teachers' answers to the subset of high-

reform response options across the two vignettes. The second measure, Reform-Full, reflects the “location” of each teacher between an “ideal” high-reform teacher and an “ideal” nonreform teacher. The ideal high-reform teacher was a simulated teacher whose self-reported likelihood of engaging in each option corresponded exactly to our judgments of reform orientation. Conversely, the ideal nonreform teacher was a simulated teacher whose self-reported likelihood was just the opposite. Analyses of the pattern of responses to these and other measures, as well as cognitive interviews conducted with a subset of teachers who described their thought processes as they answered the vignettes, suggest that the measures are providing some validity evidence about the likely use of reform-oriented instruction. The cognitive interviews also provided insights to inform potential improvements to the vignettes.

We used a multivariate linear mixed model to represent the relationship between longitudinal exposure to teacher-level predictors and student-achievement trajectories. For each outcome in each cohort, we jointly modeled test scores from the three years of the study. Scores were expressed as a linear function of overall means, adjustments for student-background variables and prior performance, current and past exposure to teacher-level predictors, unobserved random teacher effects, and residual errors that were allowed to be correlated across time within (i.e., for each) student.

We estimated the effects of teacher-level variables, including instructional practices, one at a time. That is, we started with a baseline model that includes adjustments for student demographics and year 0 (the year before the study began) achievement, and then examined the effects of a given individual teacher-level variable by augmenting the baseline model with only that particular teacher-level variable.

We report inferences about two functions of the model parameters that quantify the effects of exposure to teacher-level variables on student achievement. The first function captures the average effect of current-year exposure on current-year outcomes. The other function is the three-year cumulative exposure effect, which is interpreted as the expected difference in the scores between two students, one of whom

received above-average exposure to the particular teacher-level variable under consideration for three consecutive years, and the other one of whom received average exposure for three consecutive years.

Study Limitations

Although this study represents a methodological advance in comparison with earlier studies, it still has limitations. Stronger conclusions would have been possible using an experimental design rather than relying on naturally occurring variation. In particular, we had no control of the assignment of students to teachers during the three years of the research, and, as a result, relatively few students received either the most intensive or the least intensive exposure to reform-oriented instruction. Tracking of students in the middle schools may have confounded achievement with exposure in ways we were unable to disentangle. More-extensive use of classroom observations might provide a more accurate indication of teaching practices than do the self-report measures that were the primary tool in this study. Our experience using the vignette-based measures revealed ways these vignette-based measures might be improved in the future, as well.

Relationships Between Reform-Oriented Instruction and Student Achievement

The first research question concerned the relationships between exposure to reform practices and student achievement. We found that exposure to reform-oriented instruction generally had nonsignificant or weak positive relationships to student achievement in both mathematics and science, with the exception of groupwork-related practices in mathematics (for which the relationships were negative). Additionally, the findings suggest that relationships tend to become stronger with sustained exposure to reform teaching.

The second research question asked whether the relationship was affected by the way achievement was measured. We generally found

stronger relationships for open-ended measures than for multiple-choice measures in the sites at which both types of assessment were administered. Moreover, in the cohort with data on subscales of the multiple-choice mathematics achievement test, we found positively signed relationships to the Problem-Solving subscale and negatively signed relationships to the Procedures subscale. Together, these findings suggest that relationships between instruction and achievement can depend on how achievement is measured.

Implications

We found nonsignificant or weak positive relationships between reform-oriented instruction in mathematics and science and student achievement measured using multiple-choice tests. The relationships were somewhat stronger when achievement was measured with open-ended assessment. Additionally, in mathematics, relationships tended to be positively signed with problem-solving scores.

These findings confirm previous estimates of weak positive associations between reform-oriented instruction and achievement. The results also reinforce the message that measurement matters—i.e., that the observed relationship between reform-oriented instruction and achievement may depend on how achievement is measured. It is common practice to use existing state or district tests as measures of program effectiveness, because it is often not feasible to administer additional tests. Our analysis indicates that this decision may influence findings. It also suggests that using subscales from an existing test to produce a more refined analysis of relationships between instruction and achievement might be a good practice.

It is also important to note the influence of high-stakes accountability testing on teaching practices. Teachers reported that the testing environment influenced their use of reform-oriented practices despite the training they had received. In particular, many teachers believed that the reform-oriented practices were likely to be less effective than other kinds of practices for promoting high scores on state accountability tests. Future research on the effectiveness of reform-oriented

instruction needs to recognize that instructional reforms are not carried out in a vacuum, and it should examine the broader contextual factors as well as the specific elements of the intervention.

Perhaps the most important unanswered question regarding reform-oriented instruction concerns benefits and costs. The mathematics and science initiatives of the 1990s were relatively expensive (from the perspective of national reforms). And, although they appear to have had some effects on mathematics and science teaching, this study did not address whether these changes in practice and the associated improvements in achievement were worth the cost. Thus, it is impossible to know whether the strategy was an efficient one and should be followed in future reforms. A program of research that involves experimental studies with clear delineation of costs would provide a strong foundation for future decisions about educational reforms.