THE IMPACT OF ELEMENTARY MATHEMATICS SPECIALISTS

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Abstract

Elementary Mathematics Specialists are placed in schools to construct leadership roles and to provide on-site professional development addressing mathematical content and pedagogy in order to enhance instruction and to improve student achievement. A three-year, randomized, control study found that, over time, Specialists had a significant positive impact on student achievement in Grades 3, 4, and 5. This effect on student achievement was not evident at the conclusion of the Specialist's first year of placement. It emerged as knowledgeable Specialists gained experience and as the schools' instructional and administrative staffs learned and worked together. Specialists who were highly engaged with a teacher significantly impacted those teachers' beliefs about mathematics teaching and learning. In addition, teachers in schools with a Specialist were more likely to participate in a non-coaching professional activity (attending mathematics-focused grade-level meetings, observing peers' teaching, or attending schoolwide mathematics workshops). The Specialists in this study had substantial programmatic responsibilities that influenced their amount of available time for coaching teachers. Further, the Specialists in this study engaged in a high degree of professional coursework prior to and during at least their first year of placement. Findings should not be generalized to Mathematics Specialists or coaches with less expertise.

As suggested by a number of reports, many school districts have begun to define school-based positions wherein experienced and exceptional teachers serve as coaches and collegial mentors for elementary teachers, provide on-site professional development, and assume leadership roles for an elementary school's mathematics program [1, 2]. Frequently released from responsibility as a classroom teacher of record, these elementary Mathematics Specialists are charged with supporting teachers' knowledge of mathematics content and pedagogy, as well as fostering a coordinated vision of mathematics teaching, learning, and assessment in order to increase a school's instructional capacity [3]. The intent is to support collective professional habits that advance schoolwide growth and positively impact student achievement [4-6].

There is no single model defining the role of a Mathematics Specialist or coach, and a variety of exemplars are in place. One of the first references to this role was that of Joyce and Showers who used the term "peer coaching" to describe pairs of teachers who provided feedback and support to each other in an effort to advance their instruction [7]. Subsequently, Loucks-Horsley and colleagues wrote of "helping teachers" who provided mentoring to colleagues and fostered professional dialogue [8]. Regardless of the title and the distinctions in the job description, the common expectation is for an experienced practitioner who does not have administrative responsibility over teachers to advance instructional and programmatic change across a local school site by working with teachers individually and in grade-level teams.

There is a growing body of literature addressing the work and influence of Specialists or coaches, generally describing experienced challenges, intended practice, or perceptions of impact, more frequently in terms of reading and writing instruction rather than mathematics instruction [9]. However, this literature review identified only one refereed publication reporting a relationship between students' learning of mathematics and professional development that included coaching, but this study did not control for possible prior distinctions between groups of students either by randomization or pre-testing [10].

When whole-school mathematics coaches or Specialists are placed in a school, the ultimate intent is to positively impact student learning. Yet, one could argue that an additional measure of effect is the impact of the Mathematics Specialist on teachers' beliefs and participation in other forms of professional development addressing mathematics content and pedagogy. When elementary Mathematics Specialists work with teachers, they address the mathematical knowledge and instructional practices of teachers, but in so doing, they may also impact teachers' beliefs and influence the degree to which teachers access other avenues for professional development. Indeed, there is evidence that teachers' perceptions of mathematics teaching and learning change or persist in concert with their instructional practices [11, 12]. As such, teachers' beliefs about mathematics teaching and learning and teachers' engagement in other forms of professional development, as well as their students' achievement, are appropriate outcomes for evaluating the effectiveness of elementary Mathematics Specialists as a vehicle for school improvement.

In 2004, the National Science Foundation (NSF) funded a collaborative project involving four universities and five school districts that collected data within a three-year, randomized, control-treatment design to investigate the work and impact of full-time Mathematics Specialists in elementary schools in Virginia. This study's twenty-four treatment and twelve control schools represent a range of demographic and economic settings in urban, suburban, and urban-edge schools. The Specialists in this study were experienced classroom teachers who were selected by their school district and assigned to provide full-time support in a school after completing coursework in mathematics content and in leadership/coaching, as well as study of models, resources, and best practices for mathematics instruction. This article reports on the effects of these Specialists on teachers' beliefs and professional engagement, as well as on student achievement data in Grades 3-5 as measured by the high-stakes, standardized assessment administered in Virginia as required by federal *No Child Left Behind* legislation. As such, it characterizes the activity of Mathematics Specialists over time and provides insight regarding coaching as a vehicle for instructional reform. This article addresses the following research questions:

- What activities did elementary Mathematics Specialists engage in and what proportion of their total time did they spend completing those differing duties?
- What was the impact of elementary Mathematics Specialists on student achievement as measured by Virginia's high-stakes standardized assessment?
- What was the impact of elementary Mathematics Specialists on teachers' beliefs about mathematics teaching and learning, as influenced Specialists' degree of involvement with individual teachers?
- What was the impact of elementary Mathematics Specialists on teachers' involvement in other forms of professional development?

Method

Specialists—Five school districts in Virginia, representing urban, urban-edge, and rural-fringe communities, identified one or more triples of schools with comparable student demographics and comparable traditions of student performance on state mathematics assessments. Triples of schools, rather than pairs, were identified in order to yield comparable school placement sites for two differing cohorts of Mathematics Specialists while maintaining corresponding control sites. This study accessed Specialists who were participating in a NSF-funded teacher enhancement effort that required two cohorts of Specialists in order to develop and refine the mathematics content, pedagogy, and leadership courses completed by the Specialists.

One school was randomly selected from each of the 12 triples by the first author and was assigned a Mathematics Specialist by a cooperating school district during the 2005-06 school year. A cohort of twelve Specialists completed five mathematics content courses and one leadership/coaching course during 2004 and 2005 prior to placement, as well as a second leadership/coaching course during their first year of service as an elementary Mathematics Specialist. Of the twelve Specialists in this first cohort, eleven remained in one of the original treatment schools for three school years (August 2005–June 2008). One treatment school closed due to redistricting after the 2006-07 school year, and one Specialist in this cohort retired at that time, accepting a position as half-time supervisor of Specialists across that school district. The Specialist displaced by the school closing was reassigned to the school formerly supported by the newly retired Specialist, thus maintaining placement of a third-year elementary Mathematics Specialist across all of the remaining Cohort 1 schools during Year 3 of the study.

A second cohort of twelve Specialists completed a similar offering of these same content and leadership courses during 2006 and 2007. The first author randomly selected one of the two remaining control schools in each of the original triples of schools; these sites were identified as the Cohort 2 schools. Cooperating school districts then assigned each of the twelve Specialists in the second cohort to one of the Cohort 2 schools for two school years (August 2007– June 2009).

School districts were paid an allotment of $25,000 per coach, per year in order to offset the cost of replacement classroom teachers. Specialists were also paid an annual stipend of $2,500 for participating in the data collection phase of the study. All twenty-four Specialists were female. Eight of the Specialists are African-American; one coach is Asian; the remaining Specialists are White.

Teachers—Over the course of four years, there were 1,769 teachers of K-5 mathematics in the thirty-six cooperating schools who participated in the study. The teachers in the three cohorts of schools did not differ substantively in terms of their professional experience or demographics (see Table 1).

Table 1
Grade K-5 Teachers' Professional Demographics (2005-09)

	Cohort 1[a]			Control 1/Cohort 2				Control Throughout			
Year	05-06	06-07	07-08	05-06	06-07	07-08	08-09	05-06	06-07	07-08	08-09
Master's Degree (%)	36.4	38.2	35	40.5	46.7	45.9	46.1	35.1	40.6	41.8	42.0
Years of Teaching Experience (%)											
1 or 2 years	16.3	18.7	17.9	24.8	15.6	14.8	5.7	14.5	11.3	13.1	6.2
3 or 4 years	10.1	9.8	6.8	11.8	18.0	17.2	12.7	8.4	14.3	14.8	14.4
5 through 9 years	34.9	32.5	33.3	27.0	28.7	29.5	29.6	19.8	21.1	16.4	20.9
10 or more years	38.8	39.0	41.9	35.9	37.7	38.5	46.2	57.3	53.4	55.7	53.9
Certified Teachers (%)	98.4	95.9	96.6	94.1	94.3	95.9	95.8	93.9	94	96.7	96.1
Female (%)	93.8	93.5	92.3	83.7	86.1	83.6	85.6	87.8	86.5	88.5	87.6
Race/Ethnicity (%)											
American Indian/ Alaskan Native	0	0	0	0.7	0.8	0.8	2.2	0	0	0.8	1.0
Black/African-American	25.6	22.0	20.5	30.7	30.3	27.0	27.2	23.7	27.1	27.9	34.0
White	72.1	74.0	76.1	65.4	68.0	70.5	66.7	73.3	68.4	64.8	60.5
Asian/Asian American	0	0	0	1.3	0	0	0	1.5	2.3	1.6	0.7
Hispanic/Latino	1.6	2.4	1.7	0.7	0.8	0.8	1.6	0	0	0	0.7
More than one race	.8	1.6	1.7	0.7	0	0	1.0	0.8	1.5	3.3	2.3
n of Teachers	333	316	309	393	333	332	314	356	323	319	306

[a] 12 schools in 2005-07; 11 schools in 2007-08

<u>Data Sources: Coaches' Activity and Engagement with Teachers</u>—To account for their changing actions in school, coaches detailed the nature and duration of their daily activities using a data collection-transmittal program operating on a Personal Digital Assistant (PDA; Dell Axim X50™). The Instructional Specialist Activity Manager (ISAM) is a menu-oriented, entry interface that allows coaches to log the duration and category of their daily activity and to log a weekly reflection describing their level of engagement with particular teachers in a given week, with teacher identification cycling over the course of the school year.

Within the Daily Activity Log option of ISAM, coaches chronologically indicate the duration of an activity and then "click" the primary identification of that activity. Based on a branching network, activities of interest trigger the presentation of more detailed sub-choices which coaches again select by "clicking" on the button of interest. After entering the activity for a time period, the coaches may review and, if necessary, modify their entry. After the activities of a complete day are entered, coaches may review the day's entries and, if necessary, modify the listing prior to confirmation.

The Weekly Reflection Log lists the names of 1/6 of the teachers in a school each week, with the names cycling over a six-week period so that each teacher's name appears once in that period and six times over the course of a school year. This log asks the coaches to reflect on their interaction with a named teacher and indicate the teacher's level of engagement with the coach during group-directed, grade-level planning sessions over the past month and during individual interaction over the past ten days. As with the Daily Activity Log, coaches may review and modify their entries prior to confirmation.

Daily and Weekly confirmed data were subsequently transmitted over the Internet onto a comprehensive data management platform. This platform was housed on a server at the authors' university.

Data Sources: Student Mathematics Achievement Data—All students in Grades 3 through 8 in Virginia are expected to complete a statewide, standardized achievement test in mathematics termed the *Standards of Learning* Assessment (*SOL*) annually. Through administration of this high-stakes measure and the aligned collection of student demographic data, Virginia meets the expectations for assessment as required under the federal *No Child Left Behind* legislation. Data from the *SOL* include a total scale score for mathematics (possible scores ranging from 200 to 600) addressing content spanning: number and number sense; computation and estimation; measurement and geometry; probability and statistics; and, patterns, functions, and algebra. The *SOL* are administered annually, typically during the last half of the month of May.

While the *SOL* in Grades 3 and 5 have been administered since the 2001-02 school year, the Grade 4 *SOL* were administered for the first time during the 2005-06 school year, the first year of placement of Specialists in this study. Further, while the Grade 4 and Grade 5 *SOL* only assess content associated within the grade-level standards of that single grade, the Grade 3 *SOL* assessment measures content from Kindergarten through Grade 3. Thus, the analysis that follows separately considers the third-, fourth-, and fifth-grade students' scores across three years (2005-08).

For each grade level, the primary dependent variable was the overall *SOL* Mathematics scale score across three years. This dependent variable posed two challenges for these analyses. First, in each grade level, the distribution of test scores shifted in a non-linear fashion as the difficulty of the *SOL* Mathematics assessment varied from year to year. Second, while the range for the *SOL* scale scores was 200-600, there was a substantial but varying number of students in each year and in each grade achieving a score of 600. This ceiling effect was problematic because it increased the type II error rate, making it more difficult to detect true differences between groups. Because of these two challenges, it was not possible to standardize scores across years. Therefore, in order to control for differences in the testing year, this analysis used the scale scores in the original metric and included binary indicators for each testing year.

Ideally, an analysis examining impact of a treatment on student achievement would include student-level prior achievement in the model. However, this was also problematic, in part because of the ceiling effect and the inability to standardize scores. Further, there were no prior-year *SOL* scores for Grade 3 students in any school year or for Grade 5 students in the 2005-06 school year. In addition, when prior-year *SOL* assessments were administered, missing data due to student mobility was present and not evenly distributed across schools as coded by Title I status and minority composition.

Because controlling for student-level prior achievement was not possible, two school-level measures of the prior academic tradition were included to control for differences between schools at the extremes of the prior student achievement distribution. Low Academic Tradition and High Academic Tradition identified those schools whose mean 2004-05 *SOL* Mathematics scale scores in both Grades 3 and 5 were at least one standard deviation below or one standard deviation above the 2004-05 sample mean for all thirty-six schools.

<u>Data Sources: Teacher Beliefs Data</u>—The teachers of mathematics in the control and treatment schools completed a beliefs survey in Fall 2005, and again in Spring 2006, 2007, 2008, and 2009. This assessment was constructed using a 20-item instrument developed by Ross and colleagues with the addition of ten additional items addressing equity and directed instruction [12]. Using the 5-point Likert scale, respondents rated each of thirty statements on a scale of 1 ("strongly disagree") to 5 ("strongly agree"). The statements in the survey reflected perspectives about

mathematics curriculum and instruction, and perspectives regarding the needs of students and student understanding. Factor analysis identified two orthogonal factors: items that distinguished beliefs emphasizing directed teaching and mathematical structure as a basis for curriculum (Traditional) and items reflecting a perspective emphasizing the development of students' principled knowledge and supporting student efforts to "make sense" of the mathematics (Making Sense). Table 2 presents illustrative items from the beliefs survey. The reliability of the total 30-item scale as indicated by Cronbach's alpha is .797.

Table 2
Exemplar Items from the Beliefs Survey

Items Reflecting a Traditional Perspective Learning mathematics requires a good memory because you must remember how to carry out procedures and, when solving an application problem, you have to remember which procedure to use. The best way to teach students to solve mathematics problems is to model how to solve one kind of problem at a time.
Items Reflecting a "Making Sense" Perspective Students can figure out how to solve many mathematics problems without being told what to do. I don't necessarily answer students' math questions, but rather let them puzzle things out for themselves.

Data Sources: Teacher Professional Engagement Data—Each spring, teachers completed a survey addressing the nature and degree of their involvement in professional development over the past school year. These entries described professional development opportunities offered within and outside of schools and the amount of time spent in those activities.

Analysis and Results

Activity of the Elementary Mathematics Specialists—The ISAM Daily Activity Logs from the PDA's characterize the duration and nature of Specialists' activity across up to three years of placement in a school. Although Specialists were not expected to complete tasks related to their work responsibilities outside of their contract day, many Specialists did so. Therefore, this presentation of the activity data distinguishes between those two contexts for activity.

Table 3 presents the proportional distribution (percent) of Specialists' mean time over activity within the contracted workday for Cohort 1 and Cohort 2 Specialists. If a Specialist was absent from work on a contract day, that time is not reflected in Table 3. The mean length of a contract day for a Specialist was 7 hours, 22 minutes; the median length of a contract day for Specialists was 7.5 hours. Thus, on average, the Specialists were paid to spend 36 hours, 50 minutes at school each week with a forty-week school calendar. In terms of hours per day, the values in Table 3 may be interpolated according to the formula that 13.6% is equivalent to 5 hours per week (comparable to 1 hour per day) and 2.7% is equivalent to 1 hour per week.

Table 3

Percent of Mean Contract-Day Time over Specialist Activities by Cohort and Year

Activity	Cohort 1 2005-06 (Year 1)	Cohort 1 2006-07 (Year 2)	Cohort 1 2007-08 (Year 3)	Cohort 2 2007-08 (Year 1)
Coaching Teachers (Individual Teachers and Grade-Level Teams)	21.9	13.1	12.9	10.2
Preparing for Teaching/Coaching	11.8	12.4	12.5	11.8
Supporting Assessment	10.6	13.5	13.7	12.5
Teaching or Supporting Students (Not Demonstration or Co-Teaching)	3.0	4.4	4.5	3.6
Supporting the School Mathematics Program	5.0	4.2	5.1	5.1
Performing School-Based Duties	6.5	9.2	10.4	9.8
Materials Management/ Communication Tasks	9.7	11.0	11.8	11.4
Attending Meetings	9.2	6.8	6.7	9.5
Engaging in Personal Professional Activity	13.2	14.7	10.9	14.4
Non-Educational Activities (lunch, travel, all-school event)	9.0	10.8	11.3	11.8

The amount of contract-day time that the Cohort 1 Specialist spent coaching individual teachers decreased over the three years. The amount of time that each of the two cohorts spent coaching teachers was more consistent when the year of work was constant (both cohorts in 2007-08) than when the extent of experience was constant (Cohort 2 in 2007-08 and Cohort 1 in 2005-06). This may mean that during 2007-08 there were common outside influences impacting

Specialists' decisions as to how much available time they had to spend working with individual teachers.

Over that same time period, the amount of time that Cohort 1 Specialists spent addressing assessment increased. The Cohort 2 Specialists spent somewhat less time than the more experienced Cohort 1 Specialists addressing assessment during 2007-08, primarily because Cohort 2 Specialists had less time devoted to developing assessments and to assessment management. This may reflect the increased managerial expertise presumed of Cohort 1 Specialists during their third year of placement. The increase in Cohort 1 assessment activity and the frequency of Specialist time devoted to assessment responsibilities across the two cohorts was evident in each of the five school districts, with frequency of assessment time being a consistently modal feature of the urban districts. Because Mathematics Specialists were not assigned across all schools in a district, shifting of Specialists' time to assessment responsibilities is probably a local school response to concerns associated with assessment demands, a response that is evident within and between districts. In contrast, the increase in time Cohort 1 Specialists spent teaching or supporting students without an observing teacher present (thus not coaching through demonstration teaching, modeling, or co-teaching) varied by individual Specialists, not districts. Therefore, this was most likely a reflection of a principal's request and not a consistent response to district policy or pressure.

The time Specialists spent in meetings that did have a mathematics focus was quite consistent within districts, while being unique across districts. This indicates that a Specialist's attendance at a meeting addressing mathematics was likely not an individual decision, but reflects an expectation of either a principal or district office. As Cohort 1 Specialists gained expertise, local administrators were less likely to expect their attendance at a meeting when the agenda was not related to mathematics.

The prevalence of activity associated with personal professional development reflects the fact that all Specialists completed the second leadership/coaching course during their first year of placement. Further, many of the Specialists in each cohort completed an additional graduate course or two during their first year of placement as they completed requirements for a master's degree within the following summer or fall semester.

The amount of time that Specialists spent addressing communication, such as e-mail correspondence, was more comparable by academic year than by year of expertise. All of the participating school districts provide e-mail addresses and access to their instructional and administrative staffs. The increase in time evidenced between 2005-06 and 2007-08 is most likely a reflection of changes in school culture. In contrast, the prevalence of school-based duties is most likely a project-related artifact. The Specialists advised each other to "volunteer for bus duty" as a way to build trust and entrée into their school placements, noting that this was a time when few, if any, teachers would be available to meet with a Specialist.

The Specialists varied in terms of how much out-of-school time they devoted to responsibilities associated with their work. On average, the Specialists spent 4.5 hours a week completing work-related activity for which they were not paid. This is equivalent to approximately180 hours or twenty-four extra contract days per year.

Table 4 presents the Specialists' mean out-of-school time in hours per category of activity by school year. A substantial portion of this out-of-school time was allotted to personal professional activities. Much of this time was related to the graduate coursework that a number of Specialists were completing during their first two years of placement, as this pattern diminished markedly in the third year of Cohort 1 data entries after the degree-seeking Specialists in that cohort had completed their degrees. Materials management and communication also demanded much of the Specialists' time outside of the contracted workday. Over half of this time was spent attending to communication tasks involving e-mail, telephone calls, or the production of flyers while the remaining time was split between PDA data entry and activity associated with supporting the purchasing, distribution, and management of educational materials.

Table 4
Specialists' Mean Out-of-School Time in Hours per Activity Category by Year

Activity	Cohort 1 2005-06 (Year 1)	Cohort 1 2006-07 (Year 2)	Cohort 1 2007-08 (Year 3)	Cohort 2 2007-08 (Year 1)
Coaching Teachers	9.69	8.24	15.8	22.1
Preparing for Teaching/Coaching	31.4	26.5	18.68	11.13
Supporting Assessment	13.53	12.72	10.77	6.97
Teaching or Supporting Students (not Demonstration or Co-teaching)	4.68	4.02	3.17	1.97
Supporting the School Mathematics Program	17.05	11.28	8.17	5.97
Performing School-Based Duties	26.04	25.24	13.57	13.88
Materials Management/Communication Tasks	36.84	21.14	22.51	29.60
Attending Meetings	25.83	14.86	14.3	14.28
Engaging in Personal Professional Activity	55.53	43.98	19.4	30.02
Non-Educational Activities within Out-of-School Work Time (lunch, break, travel)	27.86	16.84	10.5	17.35
Mean Total Hours per Year	248.45	184.82	136.87	153.27

The Cohort 1 Specialists were more likely to spend their out-of-school work time preparing for coaching or teaching (demonstration teaching, modeling, or co-teaching) rather than coaching teachers, but the Cohort 2 Specialists evidenced the reverse pattern. For both cohorts, coaching time outside of the contract day was typically spent working with individual teachers, rather than with groups of teachers or grade-level teams. The out-of-school time devoted to the performance of duties almost exclusively involved monitoring students, while outside-of-contract-day work associated with the school mathematics program involved activities such as a school's annual Family Math Night.

Mathematics Achievement—In order to determine whether elementary Mathematics Specialists impacted student mathematics achievement as measured by standardized state assessments, this analysis accessed data from 24,749 student *SOL* scale scores drawn from Grades 3, 4, and 5 of thirty-six treatment and control schools over three years. Hierarchical linear modeling (HLM) was used to analyze the data. Across these three years, this sample included 1,169 teachers/classrooms of students in Grades 3, 4, and 5, of which 368 were in Cohort 1 schools, 406 were in Control 1/Cohort 2 schools, and 395 were in control schools throughout. Two analyses were conducted. The Treatment versus Control analysis compared three years of mathematics achievement scores of students in the control schools to scores of students in the treatment schools, noting whether the achievement scores of students in the treatment schools were from the three years of data from the Cohort 1 schools (2005-08) or from the one year of data from the Cohort 2 schools as collected during the third year of the study (2007-08; Cohort 2 Year 3). A second Cohort-by-Year versus Control analysis compared three years of mathematics achievement scores of students in the control schools to scores of students in the treatment schools, noting whether the achievement scores of students in the treatment schools were from the first (Cohort 1 Year 1), second (Cohort 1 Year 2), or third (Cohort 1 Year 3) year of Specialist placement in a Cohort 1 school or from the first year of Specialist placement in a Cohort 2 school (Cohort 2 Year 3) during the third year of the study.

Both the Treatment versus Control analysis and the Cohort-by-Year versus Control analysis entered identical student-level and classroom-level variables in their respective statistical models. In particular, for each grade, the analysis included controls for a student's age at the time of testing (AgeTest), as well as binary indicators to provide controls for student gender (Female), student Limited English Proficiency status (LEP), student special education status (SpecEd), student free- and/or reduced-meal status (FARM), and student minority status (Minority). The reference categories for these binary indicators were male gender and not accessing special services. The models also included two indicators to identify whether the *SOL* tests were being administered in the second or third year of the study (2007 Test and 2008 Test, respectively). The reference category for the year of the test was the first year of the study, the 2006 Test administered at the end of the 2005-06 school year. The only teacher/classroom-level variables that were significant or improved model fit were a binary indicator for teachers with master's degrees (Masters) and measures indicating years of teaching experience (1-2 Years Experience, 3-4 Years Experience, or 10+ Years Experience). The reference category for teacher experience was 5-9 years of teaching experience.

Additional school-level variables provided controls for schoolwide Title I services (Title I) and a standardized school size measure (School Size). An additional variable is the academic tradition of the school (Low Academic Tradition and High Academic Tradition).

Findings from the Treatment versus Control analysis are presented in Table 5, with the statistics for differing independent variables presented in each row and the grouped columns specifying the grade. In all three grades, the Cohort 1 coefficients were positive and significant indicating the positive impact of elementary Mathematics Specialists on student achievement. In Grade 3, students in Cohort 1 schools averaged 10.7 points, or 14% of the Grade 3 pooled standard deviation (SD) higher than the mean on the *SOL* Mathematics scaled score ($p = 0.040$). In Grades 4 and 5, students in Cohort 1 schools scored 13.7 ($p = 0.0095$) and 15.3 ($p = 0.004$) points above the mean, respectively, which corresponds to 18% SD on the Grade 4 tests and 19% SD on the Grade 5 tests. In contrast, the Cohort 2 Year 3 variable, representing the placement of a first-year coach during the third year of the study, was not significant in any of the grade-specific analyses.

Table 5
Parameter Estimates and Standard Errors for Specialist Effects on Student SOL Mathematics Overall Scale Score by Grade

Scale Score	Grade 3			Grade 4			Grade 5		
	Coefficient		SE	Coefficient		SE	Coefficient		SE
Intercept	493.95	***	2.34	470.63	***	2.45	496.95	***	2.46
Student Variables									
Age at Test	−8.49	***	1.61	−14.37	***	1.43	−13.29	***	1.56
Female	−1.86		1.26	−7.72	***	1.55	−0.69		1.64
LEP	−8.02		7.25	−18.71	**	6.33	−21.89	**	6.74
Special Education	−41.84	***†‡	3.45	−40.17	***†‡	3.30	−51.53	***†‡	4.36
Free or Reduced Meal	−17.10	***	2.20	−17.80	***†	2.41	−18.24	***†	2.78
Minority	−35.76	***	2.16	−33.74	***	2.21	−27.68	***	2.08
2007 Test	3.71		5.26	18.52	**	5.20	20.32	***	5.37
2008 Test	7.32		5.96	12.12		7.31	11.30		6.09
Teacher Variables									
Master's Degree	2.12		2.42	0.21		2.94	−5.14		3.39
1-2 years Experience	−7.87		5.15	−4.96		5.24	−13.67	*	5.98
3-4 Years Experienc	−6.54		4.27	−7.39		5.02	−6.01		5.38
10+ Years Experien	0.76		2.95	10.45	*	4.11	10.60	**	3.75
School Variables									
Title I School	7.04		5.57	4.70		5.67	12.99	*	5.34
High Academic Tradition	35.53	***	8.97	39.51	***	9.71	51.45	***	6.47
Low Academic Tradition	−13.26		7.65	−17.06	*	7.88	−2.08		9.65
School Size	−2.78		2.48	−8.43	**	2.69	−7.98	**	2.44
Cohort 1	10.71	*	5.05	13.68	**	5.17	15.25	**	5.08
Cohort 2 Year 3	−3.89		7.43	9.08		8.31	−3.16		8.74
Variance Estimates	Variance		χ^2	Variance		χ^2	Variance		χ^2
Student-level variance (σ_2)	3927.03		...	3776.08		...	4319.54		...
Class-level variance ($\tau_{00\pi}$)	382.88	***	676.93	523.16	***	518.86	554.62	***	569.58
School-level variance ($\tau_{00\beta}$)	307.98	***	288.3	277.73	***	238.65	289.61	***	207.43

*p < .05 **p <.01 ***p < .001 † Un-modeled level 2 random effect ‡ Un-modeled level 3 random effect

At the classroom level, students whose teachers had a master's degree did not have significantly different *SOL* scores than students taught by teachers without a graduate degree. The effects of teacher experience were not consistently significant across the grade-level analyses, but were in the expected direction with students with early-career teachers having somewhat lower *SOL* scores than did students of teachers with 5-9 years of teaching experience. The magnitude and significance of student achievement differences associated with teacher experience generally increased by grade.

Across all three grades, the individual effects of age, poverty, race/ethnicity, and special education status had consistently significant negative effects on total *SOL* mathematics scores ($p < 0.001$). The effects of gender and LEP status were negative, but not consistently significant. In 2007, the average *SOL* Mathematics scale score was significantly higher for Grades 4 and 5 (25% SD, $p < 0.01$). In 2008, the year-of-test effects were not significant; however, the magnitude of the coefficients underscores the importance of including these controls in the model.

The Treatment versus Control analysis did not identify a significant effect in the Cohort 2 Year 3 variable, while there was a significant positive effect associated with the Cohort 1 Specialists over the three years. The Cohort-by-Year versus Control analysis permitted an examination of whether this difference in findings reflected the differing amounts of time the elementary Mathematics Specialists in the two cohorts had to work with teachers and the school mathematics program or whether this difference reflected a cohort effect. Grade-specific findings from these analyses are reported in Table 6.

Table 6
Parameter Estimates and Standard Errors for Specialist by Year Effects on Student SOL Mathematics Overall Scale Score by Grade

Scale Score	Grade 3			Grade 4			Grade 5		
	Coefficient		SE	Coefficient		SE	Coefficient		SE
Intercept	493.91	***	2.31	470.66	***	2.50	497.05	***	2.44
Student Variables									
Age at Test	–8.50	***	1.61	–14.37	***	1.43	–13.28	***	1.56
Female	–1.86		1.26	–7.72	***	1.55	–0.71		1.64
LEP	–8.00		7.25	–18.72	**	6.33	–21.85	**	6.71
Special Education	–41.82	***†‡	3.45	–40.17	***†‡	3.30	–51.62	***†‡	4.36
Free or Reduced Meal	–17.11	***	2.19	–17.79	***‡	2.41	–18.25	***‡	2.78
Minority	–35.76	***	2.16	–33.73	***	2.21	–27.64	***	2.09
2007 Test	2.69		6.91	17.48	**	6.56	16.21	*	7.13
2008 Test	3.41		7.45	11.87		11.22	6.17		8.13
Teacher Variables									
Master's Degree	2.15		2.43	0.21		2.94	–5.03		3.37
1-2 Years Experience	–7.67		5.09	–5.00		5.27	–13.15	*	6.02
3-4 Years Experience	–6.56		4.27	–7.41		5.01	–5.98		5.31
10+ Years Experience	0.82		2.95	10.45	*	4.10	10.66	**	3.73
School Variables									
Title I School	7.23		5.71	4.57		5.66	13.49	*	5.42
High Academic Tradition	35.44	***	8.82	39.46	***	9.65	51.80	***	6.10
Low Academic Tradition	–13.88		7.89	–17.03	*	7.88	–2.77		9.53
School Size	–2.81		2.49	–8.45	**	2.70	–8.09	**	2.36
Cohort 1 Year 1	6.81		5.83	12.27		7.26	6.34		7.67
Cohort 1 Year 2	10.38		8.83	15.35	*	7.62	19.61	*	7.82
Cohort 1 Year 3	16.48		11.03	13.25		11.98	20.31	*	9.24
Cohort 2 Year 3	–1.11		8.32	8.86		10.90	–0.63		9.44
Variance Estimates	Variance		$\chi2$	Variance		$\chi2$	Variance		$\chi2$
Student-level variance (σ_2)	3926.95		…	3776.06		…	4319.37		…
Class-level variance ($\tau_{00\pi}$)	382.60	***	677.02	523.33	***	518.83	554.37	***	569.50
School-level variance ($\tau_{00\beta}$)	305.20	***	287.61	276.90	***	238.26	276.01	***	203.25

$*p < .05$ $**p < .01$ $***p < .001$ †Un-modeled level 2 random effect ‡Un-modeled level 3 random effect

A comparison of Tables 5 and 6 reveals no substantive changes in any student and classroom coefficients, except for the year-of-test control variables (2007 Test; 2008 Test). With Cohort 1-by-Year in the model, the differences between Cohort 1 and Control students' mean scale scores each year is removed from the 2007 Test and 2008 Test estimates and attributed to the year-specific Cohort 1 estimate. Thus, the 2007 Test and 2008 Test coefficients are reduced as the Cohort 1 coefficients in those years increase. This pattern is particularly evident in the Grade 4 analysis.

The Cohort 1-by-Year variables reported in Table 6 reveal a consistent pattern of results over time although, as expected, the increased variance of the estimates reduced the number of significant coefficients. In Grade 3, none of the Cohort 1-by-Year variables were significant. In the first year of the study, the *SOL* mathematics scores of the Cohort 1 students were, on average, 6.8 points (9% SD, $p = 0.25$) higher than those of the students in the control schools. In Year 2, the coefficient increases to 10.4 points (14% SD, $p = 0.24$), and in Year 3 it increases to 16.5 points (22% SD, $p = 0.14$). While increasing coefficients are apparent in the second and third years of placement of an elementary mathematics coach, the increasing Cohort 1-by-Year coefficients in this analysis are not significant, due in large part to the increased standard errors associated with this more conservative analysis.

In Grade 4, there is a similar pattern. In the first year on average, the Cohort 1 students scored 12.3 points higher (17% SD, $p = 0.09$) than the control students on the *SOL* Mathematics assessment, though this coefficient is not significant. In the second year, the coefficient was significant as, on average, Cohort 1 students scored 15.4 points higher (21% SD, $p = 0.046$) than Grade 4 students in the control schools. In the third year of the study, the coefficient for Cohort 1 students fell somewhat to 13.3 points (18% SD, $p = 0.27$), with a substantially larger standard error.

In the Grade 5 analysis, the pattern of growth is more compelling with larger and significant differences in both the 2007 and 2008 testing years. The Cohort 1 Year 1 coefficient for Grade 5 was small and non-significant at 6.3 points (8% SD, $p = 0.41$). However, during the second and third year of the placement of a coach, on average the Cohort 1 students scored 19.6 (25% SD, $p = 0.01$) and 20.3 (25% SD, $p = 0.03$) points higher respectively, than the students in the control group. Both of these estimates are statistically significant.

Across all three grades, the Cohort 2 Year 3 variable had smaller coefficients in the Cohort-by-Year versus Control analysis as compared to the coefficients in the *Treatment versus* Control analysis over three years. The reductions in these coefficients were due to the entry of the Cohort 1-by-Year variables. These more accurate Cohort 2 Year 3 estimates are consistent with the pattern of Cohort 1 coefficients, with no statistically significant improvements in student scores in the first year of coaching, with larger increases evident in following years.

<u>Teacher Beliefs</u>—In order to determine whether elementary Mathematics Specialists impacted

teachers' beliefs about mathematics teaching and learning, HLM analyses examined data from teacher beliefs surveys as collected from K-5 teachers in thirty-six treatment and control schools over four years. Across these years, this included 906 surveys from teachers in Cohort 1 schools (2005-08), 1,264 surveys from teachers in Cohort 2 schools (Control status during 2005-07; Specialist present during 2007-09), and 1,198 surveys from teachers in Control schools throughout 2005-09. Analyses were conducted on data drawn from items associated with the Traditional factor and on data drawn from items associated with the Making Sense factor.

Parallel HLM school-level and classroom-level models were applied in each analysis of beliefs data. Two school-level variables identified whether the school had an elementary Mathematics Specialist (Treatment School), as well as whether the school was a Title I school (40% or more of the enrolled students eligible for Title I services). There were five teacher-level variables: namely, a grand-mean-centered continuous variable noting years of teaching experience (Teacher Experience); gender (Female); a baseline measure of teacher beliefs on each factor as collected when a teacher entered the study (Prior Making Sense Beliefs and Prior Traditional Beliefs); and, whether a teacher was highly engaged with an elementary Mathematics Specialist (Highly Engaged Teacher). The inclusion of the variable measuring baseline teacher beliefs ensured that differences in teacher beliefs reflected changes during the time under study, rather than absolute differences in teacher beliefs that were present prior to the study and remained throughout.

While the elementary Mathematics Specialists were responsible for working with an entire school, in practice their level of engagement with teachers varied. The Weekly Reflection Logs on the PDA's provided a categorical estimation of the quantity of both individual and group-level interaction between teachers and Specialists. These reflections were entered approximately six times per year. In order to yield an annual measure of high engagement between a Specialist and a teacher, these entries were coded according to a 0/1 score (see Table 7) and summed. The proportion of these summed values to possible points (1 point per entry) yielded an Engagement rating. This proportion was then translated to a 0/1 binary measure (High Engagement) to indicate if there was or was not a high level of engagement between a teacher and a Specialist. Teachers who had an Engagement rating of 0.75 or higher were coded as 1 on the binary indicator of Highly Engaged Teacher.

Table 7
0/1 Engagement Values for ISAM Weekly Reflection Logs

	Engagement Value
Individual Engagement	
Teacher seeks the Specialist	1
Teacher is a professional colleague to the Specialist	1
Teacher supports other teachers	1
Teacher accepts the Specialist	0
Teacher avoids the Specialist	0
Teacher absent from school over past 10 days	0
Engagement During Group Planning/Team Meetings	
Teacher fully participates	1
Teacher organizes colleagues	1
Teacher contributes only when asked	0
Teacher decided not to attend a meeting	0
Teacher passively attends a meeting	0
No planning or group meeting scheduled over past 10 days	0
Teacher was not available to attend a meeting	0

These models explained all of the between-school variation and 41% of the individual variation on the Traditional beliefs factor and 37% of the variation between individuals on the Making Sense factor.

As reported in Table 8, the most powerful teacher-level predictor of teacher perspectives on the Making Sense factor was a teacher's baseline Making Sense factor score. Teachers whose baseline Making Sense scores were 1 SD higher than the mean at the initiation of the study had, on average, 59.3% higher scores on the final Making Sense measure. The indicator for Title I was significant and negative, indicating teachers in Title I schools actually had a moderately lower Making Sense factor score by about 15% SD (-21.2% + 6.2%). While, on average, teaching experience did not significantly impact Making Sense factor scores (an increase of 0.2% per year of teaching experience), each year of teaching experience in Title I schools was associated with an additional 0.6% SD decrease in the Making Sense factor score per year of experience. Beliefs of teachers in schools with an elementary school Mathematics Specialist did not differ significantly in terms of the Making Sense perspective from those teachers in the Control schools, unless the teacher was highly engaged with the Mathematics Specialist. Teachers who were highly engaged with their Mathematics Specialist had, on average, a statistically significant 12.5% SD higher measure on the Making Sense beliefs scale.

Table 8
Effects of Elementary Mathematics Specialists on Teacher Beliefs Reflecting a Making Sense Perspective

	Coefficient	Standard Error	
Intercept	.062	.014	***
Treatment School	.009	.031	
Title I School	–.212	.028	***
Teaching Experience	.002	.001	
Title I School	–.006	.003	*
Female	.015	.004	***
Prior Making Sense (Baseline)	.593	.014	***
Teacher Highly Engaged with an Elementary Mathematics Specialist	.125	.037	***
Variance Estimates	Variance		$\chi 2$
Reliability (λ)	.883		
Teacher Level Variance (σ^2)	.914		
School Level Variance (τ_{00})	.081		95.61
ICC (ρ)	.081		
Final Teacher Level Variance (σ^2)	.575		
Teacher Variance Explained	37.1%		

$*p < .05$ $**p < .01$ $***p < .001$

Note: Schools' Title I status explained enough of the differences between schools on the intercept that there were no longer significant differences between schools. Thus, this model has no random effects and coefficients are OLS estimates.

In the analysis of the Traditional beliefs data, the baseline measure of Traditional beliefs was the most powerful predictor in the model indicating that a standard deviation increase in the initial measure of Traditional beliefs was associated with a 67.5% SD increase in the final measure (see Table 9). Teachers who taught in Title I schools were substantively more likely to have Traditional beliefs by 33.5% SD (-3.7% + 37.2%). While, on average, teaching experience did not significantly impact Traditional factor scores (a decrease of 0.2% per year of teaching experience), each year of teaching experience in Title I schools was associated with a significant additional 0.6% SD increase in the Traditional factor score per year of experience. These results indicate that teachers in Title I schools held much more traditional beliefs than their counterparts in non-Title I schools and these differences became more pronounced with increasing years of teaching experience.

Table 9
Effects of Elementary Mathematics Specialists on Teacher Beliefs Reflecting a Traditional Perspective

	Coefficient	Standard Error	
Intercept	–.037	.012	**
Treatment School	–.029	.027	
Title I School	.372	.028	***
Teaching Experience	–.002	.001	
Title I School	.006	.002	*
Female	–.011	.003	**
Prior Traditional (Baseline)	.675	.014	***
Teacher Highly Engaged with an Elementary Mathematics Specialist	–.091	.033	**
Variance Estimates	Variance		$\chi 2$
Reliability (λ)	.971		
Teacher Level Variance (σ^2)	.762		
School Level Variance (τ_{00})	.302		95.61
ICC (ρ)	.284		
Final Teacher Level Variance (σ^2)	.448		
Teacher Variance Explained	41.2%		

* $p < .05$ **$p < .01$ ***$p < .001$

Beliefs of teachers in schools with an elementary school Mathematics Specialist did not differ significantly in terms of the Traditional perspective from those teachers in the control schools, unless the teacher was highly engaged with the Mathematics Specialist. Teachers who were highly engaged with their Mathematics Specialist had, on average, a 9.1% SD lower measure on the Traditional beliefs scale, a statistically significant difference.

Teacher Engagement in Other Professional Development—To investigate the effects of elementary Mathematics Specialists on teachers' professional development, a parallel model was fit to three dependent variables indicating whether a teacher attended a mathematics-centered grade-level meeting, whether they observed a colleague teach a mathematics lesson, and whether they attended a schoolwide mathematics instruction workshop. Since these were binary outcomes, the analyses fit hierarchical linear models with a Bernoulli distribution and a logit link function. These models return logit coefficients which, unlike probabilities, are additive. These logit coefficients were converted into the probabilities that teachers would engage in different types of professional development based on a number of characteristics. These characteristics included four individual variables and three school-level variables. The four teacher-level measures were: the final Traditional and Making Sense beliefs scales, a binary indicator for novice teachers (1-2 years of experience), and a binary indicator for African-American teachers. Originally, all races were included in the model, but only African-American teachers showed differences, and the proportion of teachers whose race/ethnicity was neither White nor African-American was very small. The models also included three school-level binary variables (Treatment schools, Title I schools, and Title I Treatment schools).

Table 10 presents results of these analyses for three dependent variables (Attending mathematics-centered grade-level meetings; Observing a colleague teach mathematics; Attending a school-based mathematics workshop) with three sets of columns. The first and second columns of statistics in each set present the logit coefficients and the standard errors associated with each variable; significant coefficients are marked in the table with asterisks. The third column in each set presents the probabilities for each variable, calculated by summing the logit coefficients that apply for each significant coefficient. For example, in the middle set of statistics, the probability of observing a colleague for a teacher in a treatment school is calculated by summing the logit coefficients for the intercept and the Treatment variable, and converting that sum to a probability. Likewise for teachers in a Title I Treatment school, which is an interaction term, the coefficients for all the constituent variables—Treatment, Title I school, and Title I Treatment school—are added to the intercept and then converted into a probability. Thus, while positive logit coefficients indicate increased probabilities and negative logit indicated decreased probabilities, only summed probabilities can be compared directly to the intercept. These probabilities indicate the relative power of each significant variable, and are not recorded for non-significant variables.

Table 10
Effect of Elementary Mathematics Specialists on the Probability of Teachers Engaging in Professional Development

	Attend Mathematics-Centered Grade-Level Meetings				Observing a Colleague Teach				Attend a School-Based Mathematics Workshop			
	Coefficient		Standard Error	Summed Probability	Coefficient		Standard Error	Summed Probability	Coefficient		Standard Error	Summed Probability
Intercept	1.504	***	.116	.818	–.107		.079	.473	.396	***	.078	.598
Treatment School	1.090	**	.384	.93	.758	***	.270	.657	.747	**	.262	.758
Title I School	.320		.388		.843	**	.279	.676	.896	**	.273	.785
Title I Treatment School	–1.028		.544		–.761		.383		–1.100	**	.376	.719
Making Sense Beliefs	.326	***	.049	.860	.270	***	.041	.541	.256	***	.041	.657
Traditional Beliefs	.021		.057		.154	***	.044	.512	.132	**	.045	.629
Novice Teacher (1-2 yrs)	–.398	***	.121	.752	.345	***	.103	.559	–.134	***	.103	.561
African-American Teacher	.283	*	.121	.857	.405	***	.100	.574	.308	**	.103	.669

* $p < .05$ **$p < .01$ ***$p < .001$

Each of the three intercept values in Table 10 indicates the average probability that a teacher engaged in a given category of professional development. Teachers were highly likely to attend a mathematics-focused, grade-level meeting (81.8% probability), were more likely than not to report attending a school-based mathematics workshop (59.8%), and slightly less than likely to observe a peer teach a lesson (47.3%). Individual teacher beliefs influenced teachers' engagement in professional development, as teachers with a Making Sense perspective were somewhat more likely to engage in all types of professional development, while Traditional beliefs evidenced a slightly lesser influence, with no significant impact on grade-level meeting attendance. During their first two years of teaching, teachers were significantly more likely to observe other teachers teaching (55.9% - 47.3% = 8.6%), but slightly less likely to take advantage of other professional development opportunities. African-American teachers were consistently more likely to attend all types of professional development sessions.

School-level variables consistently influence attendance at professional development sessions. Teachers in schools with elementary Mathematics Specialists were more likely to attend all three forms of professional development as compared to teachers in control schools. The likelihood of peer observations and local-school workshop attendance was higher in Title I schools by 20.3% and 18.7%, respectively. There were no differences in the likelihood of teacher attendance at mathematics grade-level meetings or peer observations between Title I and non-Title I Treatment schools. However, teachers in Title I schools with an elementary Mathematics Specialist were slightly less likely to attend school mathematics workshops, though still 12.1% (71.9% - 59.8%) more likely to attend than teachers in control, non-Title I schools.

Discussion

This study found that elementary Mathematics Specialists had a significant positive impact on student achievement over time, but this effect only emerged as knowledgeable Specialists gained experience and as schools' instructional and administrative staffs learned and worked together. Simply allocating funds and then filling the position of an elementary Mathematics Specialist in a school will not yield increased student achievement. The Specialists in this study influenced the beliefs about mathematics teaching and learning held by the teachers with whom they were highly engaged, increasing a Making Sense perspective and diminishing a Traditional perspective. Further, teachers in the schools with an elementary Mathematics

Specialist were more likely to engage in other forms of available professional development addressing mathematics content and pedagogy than were teachers in the control schools.

As inferred from the PDA data, the Specialists in this study were more likely to focus their coaching efforts on individual teachers, rather than on leading grade-level planning teams. The time that Specialists had to coach individual teachers seemed to diminish over the three years of PDA data collection, while the time that they devoted to supporting student assessment demands increased. While this pattern was evident across schools in each of the five cooperating school districts, each year there were one or two schools in urban districts (identity of schools varied by year) where not only was time allocated to managerial aspects of assessment, but increased time was also spent working with students without an observing teacher. It is recognized that if a teacher is absent on a given day, many administrators will request that the school's Mathematics Specialist, rather than the assigned substitute teacher, teach the mathematics lesson to the absent teacher's class on that day. However, this practice is not unique to urban districts. Thus, that is not likely to be the explanation for this pattern. It may be that if a Specialist devoted an unusual increase in time for assessment and independent instructional roles in a given year, it was in response to her local school's administrative expectations.

All of the elementary Mathematics Specialists in this study were responsible for coaching teachers of mathematics in their schools, but they also had programmatic responsibilities. These responsibilities included assisting the administrative staff in interpreting assessment data, ensuring that their schools' curriculum was aligned with district and state standards, working to foster home/school/community partnerships focused on students' learning of mathematics, and collaborating with their principal to support a schoolwide mathematics program.

The Specialists who were the subjects of this study engaged in substantive academic coursework that was designed to foster and support their transition to the position of whole-school elementary Mathematics Specialist. As such, the results herein should not be generalized to other settings where an experienced teacher is simply named as the school-based Mathematics Specialist or coach with little or no prior professional development addressing the responsibilities and expertise presumed of elementary Mathematics Specialists or coaches. Further, there have been recent recommendations that schools employ a specialized teacher model, particularly in the upper elementary grades, in which all students receive their mathematics instruction from a mathematically well-prepared teacher [13]. While this study and many of the school districts cooperating in this study used the term "mathematics specialist," the model of a specialized teacher for instruction was not implemented in this study.

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