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Organizing for instruction in education systems and school organizations: *how* the subject matters

JAMES P. SPILLANE and MEGAN HOPKINS

Teaching, the core technology of schooling, is an essential consideration in investigations of education systems and school organizations. Taking teaching seriously as an explanatory variable in research on education systems and organizations necessitates moving beyond treating it as a unitary practice, so as to take account of the school subjects implicated in the work. Building on and extending earlier work, in this paper we examine subject matter differences in how one education system (Local Educational Agency) and its elementary schools organize for instruction in the core elementary school subjects. Specifically, this paper explores how education leaders and teachers in one local American school district interact with one another with respect to advice and information about teaching and learning in literacy, mathematics and science. We examine similarities and differences in school staff members' advice and information networks and consider how these differences relate to the formal organizational infrastructure intended to support instruction.

Keywords: instructional improvement; instructional systems; school organization; school subject matter; social networks

Teaching is still on the sidelines in scholarship on education systems and school organizations. It is typically treated as an outcome variable with relatively few studies including it as a potentially powerful explanatory or independent variable. There are some exceptions, in particular work that examines the subject matter context of high schools or secondary schools (Ball 1981, Ball and Lacey 2012, Grossman and Stodolsky 1994, Horne 2005, Little 1993, McLaughlin and Talbert 1993, Siskin 1991, 1994). At the same time, research also suggests that the school subject is an important consideration in understanding how elementary school teachers think about instruction and its improvement (Drake *et al.* 2001, Spillane 2000, Stodolsky 1988), as well as how elementary schools lead and manage teaching and learning efforts (Spillane 2006).

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Based on a longitudinal mixed methods study of one American school district and its 14 elementary schools, in this paper, we examine how school staff organized for instruction in the three core elementary school subjects: literacy, mathematics and science. Specifically, we examine advice and information interactions related to teaching and learning in these three subjects, identifying similarities and differences in the relational structure of these instructional advice and information networks and working to explore relations with formal organizational structure, or what we refer to as system and organizational infrastructure.

We focus on advice and information interactions for three reasons. First, advice and information are the building blocks of knowledge development, and new knowledge is one of two core ingredients in improving instructional productivity commonly referred to as skill and will (i.e. motivation) (Darling-Hammond *et al.* 2009, Elmore 1996, Hill 2004). Second, there is solid empirical evidence of teacher peer effects; that is, that interactions among teachers about instruction do matter to their instructional productivity (Jackson and Bruegmann 2009). Third, research has shown that advice and information interactions are in many ways related to the broader institutional context (Burch and Spillane 2005) and to the formal organizational structures that are embedded within local school systems (Hopkins *et al.* in press, Spillane and Kim 2012, Spillane, Parise, and Sherer 2011, 2012).

Based on our analysis, we argue that the school subject matters in how education systems and schools organize for instruction. Further, we argue that these differences are partially explained by how the education system deploys resources and designs its infrastructure to support instruction differently by school subject. Our central argument is this: how school systems organize for instruction differs depending on the school subject, but these differences are at least in part a function of the design decisions of system leaders. In concluding, we argue for more sophisticated constructions of teaching that take the school subject into account in research and development work on school systems and organizations. Theoretical and empirical work on school systems and school organizations and their relations to the core technical work of schooling—instruction—must take the school subject into consideration because instruction is not a generic or monolithic variable but rather a *subject specific one*.

Our paper is structured as follows. We begin by anchoring our work in the theoretical and empirical literature that frames our analysis. We then discuss the mixed methods research methodology that was the basis for our theory-extending work. Turning to findings, we advance and support two main propositions or working hypotheses about relations between school subjects and how systems and organizations organize for instruction. First, we document substantial differences in school staff instructional advice and information interactions by school subject. Based on this analysis, we argue that how schools organize for instruction depends on the school subject. Second, we associate subject-specific differences in advice and information interactions about teaching and learning with the organizational infrastructure, in particular formally designated leadership positions. We do so by documenting how the

organizational infrastructure differed by school subject and by showing how changes to the school infrastructure contributed to changes in advice and information interactions about teaching and learning in mathematics. We conclude with a discussion of the implications of our analysis for research, policy and practice.

Empirical and theoretical anchors

Our work is motivated and framed by theoretical and empirical work in two traditions. First, we motivate and anchor our work in research that points to the importance of teachers' interactions with peers for their learning and development, and how the organizational infrastructure influences or structures these interactions. Second, we motivate and frame our work with research on how school subjects matter in classroom, school and institutional work related to teaching.

Teacher learning from peer interactions

Various lines of education research have theorized and documented teachers' on-the-job learning from their interactions with peers (Eraut 2004, Eraut and Hirsh 2007, Frank *et al.* 2004). Research on teacher collaboration suggests that when teachers share expertise, talk about new material, discuss effective teaching strategies and encourage experimentation around new initiatives, they create opportunities to learn (Brownell *et al.* 1997, Davis 2003, Little 2003, Smylie 1995). Recent work has highlighted the benefits of teachers' learning for students, where higher levels of teacher collaboration were associated with higher student achievement on high-stakes tests in both math and reading, after controlling for school and individual factors (Goddard *et al.* 2007). Studies have also suggested that social interactions, advice-seeking interactions specifically, are associated with the transfer of information, essential for learning and knowledge development (Frank *et al.* 2004, Reagans and McEvily 2003). Strong ties support teachers' joint sense-making about instructional policy and reform (Coburn 2001, Spillane 1999). Moreover, social interactions that span an organization's boundaries may also be important for teacher learning because they can provide access to new information and potentially minimize conformity and group think among organizational members (Leana and Pil 2006, Reagans and McEvily 2003).

Scholars have also examined how school organizational conditions influence teacher learning and instructional change (Bryk *et al.* 1999, Louis *et al.* 1996, McLaughlin and Talbert 2001, Scribner *et al.* 1999, Wilson and Berne 1999). School norms of trust among staff, collective responsibility for student learning and openness and innovation enable on-the-job learning (Bryk and Schneider 2002, Lee and Smith 1996, Louis *et al.* 1996, Rosenholtz 1985, Scribner *et al.* 2002, Smylie 1995, Tschannen-Moran 2001). Further, there is evidence that school leaders who encourage knowledge sharing among school staff and create

organizational infrastructures that promote collaboration are more effective in fostering changes in teaching practice (Bryk *et al.* 1999, Bryk and Schneider 2002, Fullan 2002, Youngs and King 2002).

There is also evidence suggesting that schools with norms that support teacher interactions about instruction are more effective in fostering instructional change and improving student achievement (Bryk *et al.* 1999, Louis and Marks 1998). One study, for example, revealed that teachers' on-the-job learning opportunities (as well as their formal professional development) in both mathematics and literacy were significantly associated with changes in teachers' practice in those two subjects (Parise and Spillane 2010). Another study marshaled strong causal evidence that teachers learn from one another, where teachers with more effective peers were themselves more effective in the classroom; teachers' learning from peers accounted for 20% of the variation in their instructional effectiveness as measured in terms of student achievement (Jackson and Bruegmann 2009). Thus, teachers' effectiveness at raising test scores was at least in part due to learning from their colleagues. More recent work has replicated this finding (Goldhaber and Hansen 2010).

However, interactions among teachers that support learning and development are not natural occurrences. Rather, the frequency and content of interactions among school staff about teaching are related to the broader institutional and political context that privilege specific foci within different school subjects (Burch and Spillane 2005). Moreover, a growing body of literature has shown that school staff interactions about teaching are in many ways associated with how local school systems arrange formal organizational structures at the system and school levels (Hopkins *et al.* in press, Spillane and Kim 2012, Spillane *et al.* 2012, Spillane, Parise, and Sherer 2011). For example, while individual-level characteristics like race and gender predict interactions about teaching and learning, organizational-level factors also matter, such as whether or not school staff members hold formally designated leadership positions or teach at the same grade level (Spillane *et al.* 2012). Further, there is some evidence that changes to a school system's infrastructure, such as integrating professional development or hiring instructional leaders, can promote interactions about teaching among school staff members (Hopkins *et al.* in press).

Taken together, this work suggests that teachers' on-the-job interactions with colleagues are important for fostering their learning about instruction. At the same time, the available literature suggests that whether and how teachers interact with one another about instruction is likely to vary depending on district and school infrastructures as well as on the school subject, which we discuss further below.

School subjects and organizing for instruction

A substantial body of research, mostly at the secondary school level, suggests that school subjects and teachers' perceptions thereof shape teachers' work and their response to efforts at reforming their practice (Ball 1981, Ball and Lacey 2012, Grossman and Stodolsky 1994, Little

1993, McLaughlin and Talbert 1993, Siskin 1991, 1994). Secondary school teachers differ in their conceptions of the subjects they teach, and these differences have consequences for curricular practices such as teachers' control of content and curriculum coordination and standardization, differences that may mediate the influence of reform on teaching practice. Subjects vary on dimensions that include their definition, scope, sequencing of material and whether the subject is static or dynamic (Stodolsky and Grossman 1995). Such differences might be expected, considering that most secondary teachers are subject matter specialists rather than generalists.

Even more important, although elementary or primary school teachers are typically generalists without well-defined subject matter specializations, the subject matter is an important influence on their practice (Stodolsky 1988) and their efforts to reconstruct that practice (Drake *et al.* 2001, Spillane 2000). Further, there is evidence to suggest that how teachers and school leaders organize for instruction, including teachers' interactions about teaching and learning and school leaders' participation in formal organizational routines, also differs by school subject (Hayton and Spillane 2008, Spillane 2005). Finally, the institutional sector also treats school subjects differently, with some subjects—most notably mathematics and literacy—receiving considerably more attention from policy-makers and other institutional actors than other subjects such as science and social studies (Burch and Spillane 2005). In short, the school subject appears to be an important consideration in all three levels of 'curriculum-making'—institutional, programmatic and classroom (Deng 2009, Deng and Luke 2008). As such, in this paper, we examine how school staff interactions about teaching and learning differ depending on the school subject, and how the school system's infrastructure supports or constrains subject-specific interactions.

Methods

Data for our analysis were drawn from a social network survey collected over three years in one mid-sized suburban Midwestern school district in the USA that we refer to as Auburn Park. A School Staff Questionnaire (SSQ) was administered every spring from 2010 to 2012 to all teaching and administrative staff members in all of the district's elementary schools. In this paper, we use data from the social network survey items in 2010 and 2012 to explore advice- and information-seeking interactions (also referred to as simply advice interactions for readability) among school staff in the three core elementary subjects: literacy, mathematics and science. We also used interview data from a purposeful sample of schools and staff.

In 2012, 5786 students were present in Auburn Park's 14 elementary schools, which ranged in size from 259 to 564 students (see table 1). While all schools served predominantly white student populations, their socioeconomic makeup varied, from 5 to 58% of a school's students receiving free or reduced-price lunches.

Table 1. Elementary school demographics, Auburn Park School District, 2012.

School	Students enrolled	White (%)	African American (%)	Latino (%)	English learner (%)	Free/reduced lunch (%)	Staff in network
<i>Kingsley</i>	564	89	2	4	–	7	32
<i>Chamberlain</i>	528	91	3	3	–	5	30
<i>Ashton</i>	484	74	5	12	7	40	31
<i>Ashe</i>	464	88	2	5	–	7	27
<i>Warner</i>	446	84	7	2	4	18	27
<i>Abbott</i>	441	93	1	4	–	23	24
<i>Bryant</i>	436	81	6	8	–	39	34
<i>Riley</i>	403	89	4	3	–	28	26
<i>Northvale</i>	395	86	4	5	–	14	22
<i>Torres</i>	393	76	9	8	9	44	29
<i>Cisneros</i>	353	88	3	4	–	16	22
<i>Chavez</i>	343	71	11	11	8	58	28
<i>Stevenson</i>	277	69	10	10	9	48	22
<i>Easton</i>	259	83	3	5	–	10	17

Notes. A missing value indicates that data were masked to protect student identity, as fewer than 10 students were reported in the subgroup. Schools in italics were interview sites.

Social network survey

The SSQ included items related to school culture and instructional leadership, as well as advice- and information-seeking interactions in core school subjects, which are the focus of the present analysis. In order to conduct reliable and comprehensive analyses of staff interactions, high response rates are necessary, preferably 80% or higher (Kossinets 2006, Wasserman and Faust 1994). In 2012, response rates ranged from 78 to 100% in Auburn Park schools, with an overall response of 94% and a total of 371 staff member responses. In 2010, 331 staff members responded to the survey, with an average response rate of 81%.

Using social network survey items that were developed, piloted and validated in other studies (Pitts and Spillane 2009, Pustejovsky and Spillane 2009), we asked respondents: ‘During this school year, to whom have you turned to for advice and/or information about curriculum, teaching, and student learning?’ Survey respondents listed up to 12 individuals, and these names were auto populated in a follow-up question that asked respondents to indicate the content area for which they sought advice and/or information from each person listed. In 2010, respondents were asked this question with respect to reading/English language arts (which we refer to as ‘literacy’ throughout this paper) and mathematics. In 2012, science was added to this item. Thus, we present comparative cross-sectional data related to literacy, mathematics and science in 2012, yet can offer comparisons over time in literacy and mathematics only.

Social network measures

We used the social network data to calculate two network-level measures pertaining to relational structure. First, the *gini coefficient* measures the

extent to which actors are part of the network's core versus on the network's periphery (Borgatti and Everett 1999). In essence, the gini coefficient indicates the amount of inequality in a network (Allison 1978). If all network actors have the same score with an equal number of ties directed toward them, the gini coefficient would equal 0 indicating complete equality. Conversely, if a single actor has a score of 1, meaning that all ties are directed toward him or her, the gini coefficient would equal 1 and indicate total inequality. Second, network *density* is a measure of the proportion of potential ties between actors in the network that are actualized; it is the total number of ties divided by the total number of possible ties. For example, if every staff member has a tie to every other staff member, the density would be 1.0. If one-quarter of the possible ties are actualized, the density would be 0.25.

We also calculated three individual-level measures using the social network data. *Degree centrality* measures network activity and centralization (Freeman 1979) and assumes that actors who are better connected are more central than others in the network. An actor's degree centrality equals his or her total number of network relations. For directed network data, we can measure *in-degree* and *out-degree centrality*. In-degree equals the number of people who sought out a particular actor for advice or information, and out-degree equals the number of people that particular actor sought out him or herself. Next, *betweenness* is a measure of brokering, or the extent to which an actor links two other actors in a network (Freeman 1979). Specifically, betweenness measures the number of times a vertex occurs on a geodesic. For a given node A, betweenness is calculated as the number of geodesic paths from B to C that pass through A. As such, if an actor has a betweenness of 10, then there are 10 instances in which that person links two distinct actors in the network.

Formal system and organizational infrastructure measures

Although we acknowledge that there are several dimensions of the formal system and organizational infrastructure within schools, such as standards, curricula, professional development and organizational routines (Cohen and Moffitt 2009, Hopkins *et al.* in press, Spillane *et al.* 2011, 2012), we built on prior work (Spillane and Kim 2012) and focused on formally designated positions. First, we considered those staff members who held *full-time leadership or specialist positions*. In all study years, these included school principals, whose main responsibility was administration rather than teaching, as well as 14 literacy facilitators, whose primary roles were as coaches to support teachers at their schools in developing their literacy instruction. In literacy, five schools also had reading specialists, whose responsibilities included full-time intervention focused on struggling readers. Additionally, two schools (Bryant and Chamberlain) had math facilitators starting in 2011 who focused on supporting instructional improvement in mathematics.

Second, we considered *teacher leaders*, or classroom teachers who held a leadership role at their schools, such as a programme coordinator,

grade-level team leader, mentor teacher or district curriculum committee member. While about 25% of these teacher leaders received a few hours of release time to assume leadership responsibilities, the vast majority did not. Because there were no significant differences in the advice interactions of these teacher leaders, we considered them as one group. Schools varied in their number of teacher leaders, from 16 to 38% of staff members designated as such leaders. Third, we considered *full-time teachers* who did not indicate having any type of leadership designation.

Social network data analysis

To examine similarities and differences in the structure of teaching advice networks between the school subjects, we first calculated gini coefficients and densities for schools' literacy, mathematics and science networks in 2012 using UCINET software (Borgatti *et al.* 2002). Then, we calculated individual centrality measures (i.e. in-degree, out-degree and betweenness) for all survey respondents in 2012 and calculated averages across the district for each measure using STATA software version 12.¹ To explore how the formal structure mattered for how school staff interacted in particular subject areas, we examined these three centrality measures for each school subject by position type (i.e. full-time leaders and specialists, teacher leaders and teachers). We then compared average centrality measures between these groups using one-way analysis of variances (ANOVAs) with permutation tests. Given that observations based on social network data are not independent, we used a random replication procedure with 5000 permutations for generating significance levels so that standard assumptions of independence and random sampling were not required (Carrington *et al.* 2005).

To illustrate trends from the district data, we present social network diagrams (using NetDraw (Borgatti 2002)) as well as average network measures for two case schools: Kingsley and Chamberlain. We selected these two schools because they each represented a different formal structure in 2012, as Chamberlain had a math facilitator and Kingsley did not, and because they had similar student populations (see table 1). These schools allowed us to examine more closely the similarities and differences in advice networks across the three subjects and to understand how shifts in the formal structure were related to changes in school staff interactions.

Staff interviews

As a follow-up to staff surveys, a sample of schools, teachers and administrators were selected for semi-structured interviews in spring 2011 and 2012. We selected five schools (as noted in italics in table 1) to represent a range of formal organizational structures, such as schools with and without math facilitators. We interviewed the principal and four to seven teachers per school, for a total of 33 interviews. We included teachers

from different grades as well as teachers who were integrated and some who were isolated in school staff advice networks.

The interview data were used primarily to supplement the social network data and findings. Given the project's overall focus on mathematics instruction, the interviews tended to focus on advice interactions about that subject. However, for this paper, we coded the data broadly to capture the ways in which school staff described their interactions in math, literacy and science and to identify examples that could serve as illustrations of the phenomena emerging from the quantitative data.

Limitations

Our work is limited in that we do not attend to classroom teaching or changes in teachers' instructional practice; however, prior research suggests that there are important differences in teaching between the school subjects (Ball 1981, Ball and Lacey 2012, Drake *et al.* 2001, Grossman and Stodolsky 1994, Little 1993, McLaughlin and Talbert 1993, Siskin 1991, 1994, Spillane 2000, Stodolsky 1988). Future research might systematically examine how the subject matters across curricular levels (Deng 2009, Deng and Luke 2008) by exploring the relationships between classroom-, school-, and system-level practice and how each of these levels matters for instructional improvement.

Subjects, systems and school organizations

We organize our findings like this: First, based on our analysis, we argue that advice interactions about teaching and learning in Auburn Park elementary schools differed by school subjects in terms of advice seeking, providing, brokering and the presence of central advice givers. Second, we show how the system and organizational infrastructure, specifically formally designated leadership positions, is associated with advice interactions by school subject. Third, capitalizing on changes in the formal infrastructure, in particular the introduction of math facilitators in a subset of Auburn Park elementary schools, we empirically examine whether and how these infrastructural changes were associated with changes in advice interactions among elementary school staff.

Instructional advice and information interactions: the subject matters

Advice and information are key building blocks in developing knowledge about instruction, a key ingredient for instructional improvement. A teacher, for example, may develop new mathematical pedagogical knowledge or science content knowledge as a result of new information or advice provided by a more expert peer. Similarly, two teachers, in exchanging information about the teaching of writing, may develop new knowledge about writing instruction as a result of combining their respective

information. Teachers not only learn from formal professional development, but also from their on-the-job interactions with peers (Jackson and Bruegmann 2009, Parise and Spillane 2010). Thus, instructional advice and information interactions are an important consideration, and prior work suggests that these interactions may vary depending on the school subject (Burch and Spillane 2003, Spillane 2005).

Our analysis suggests that interactions among elementary school staff about teaching differed on several dimensions depending on the school subject. To begin with, teachers and leaders communicated with more of their colleagues about teaching and learning related to literacy than to mathematics or science. School literacy networks were on average 50% denser than mathematics networks and 150% denser than science networks. Further, mathematics networks were 66% denser than science networks. These differences varied by school, where literacy networks were between 8 and 92% denser than math networks, and math networks were between 17 and 136% denser than science networks. More specifically, the average density of school literacy networks was 0.090 across the district, compared to 0.060 in math and 0.036 in science. Schools varied in their network densities, from 0.055 to 0.157 in literacy, from 0.037 to 0.092 in math and from 0.024 to 0.053 in science. Overall, our analysis suggests that there were more interactions about literacy teaching than mathematics and science teaching. Similarly, there were more advice interactions about teaching mathematics than about teaching science.

To get a sense of these subject matter differences, consider the advice networks for Kingsley Elementary School in 2012 (see figure 1). While the school had a literacy facilitator, no subject-specific leaders were assigned to other subjects. At Kingsley, school staff were more likely to be connected to one another in literacy than in mathematics or science. While all staff members belonged to the teaching advice network for literacy, two staff members did not belong to the advice network for mathematics, and seven did not belong to the advice network for science. Further, the fragmentation of these advice networks increased from literacy to mathematics and science. In the science network, Kingsley staff members were divided into five distinct groups, whereas they comprised single groups in the literacy and mathematics advice networks. At the same time, the mathematics network was more susceptible to fragmentation than the literacy network. For example, in the school math network, a single first-grade teacher connected the primary elementary grades with the upper elementary grades by brokering relations between a third-grade and a sixth-grade teacher (see figure 1). Removal of this teacher would have resulted in the division of the mathematics network into two distinct groups. Finally, there were more closed triads among school staff members in literacy than mathematics or science. In closed triads, two actors in a network who are tied to a third actor are also tied to each other. These relationships are thought to be long lasting and more influential than other types of ties (Krackhardt 1998, Simmel 1950), and to facilitate the development of trust and cooperation (Coleman 1990). At Kingsley, there were 61 closed triads in literacy, compared to 18 closed triads in mathematics and just 9 in science. Thus, not only were staff interactions

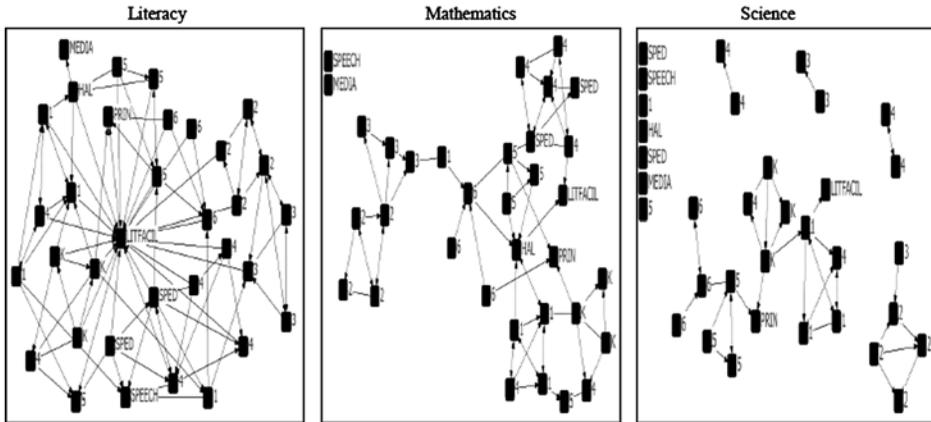


Figure 1. Kingsley elementary school (no mathematics facilitator) social network diagrams by subject, 2012.

about literacy teaching more numerous, but they also had the greatest potential for cooperation and influence.

Our interview data supported these findings. As a teacher at Kingsley noted: ‘We’ve had such an emphasis on language arts that we kind of feel like math sometimes has been the fair-haired orphan. So, now we’re trying to bring math back up because it’s one of the essential things that children need to do’. This teacher described the need for a renewed focus on mathematics, given the lack of attention to the subject in previous school years. In her conceptualization, however, only literacy and math are described as ‘essential things that children need’ and the other school subjects, like science, were not included. Staff members at other schools also described an overall emphasis on literacy and the exclusion of other subjects. For example, the principal at Chavez Elementary School shared: ‘I think what I’m struggling with is just that in our district and in our building, our concern has been reading and writing for so long that our math discussions are much more limited’.

One potential explanation for these subject matter differences in advice networks is that school staff were, in general, more likely to seek out advice about teaching literacy than other school subjects (Hayton and Spillane 2008, Spillane 2005). Our analysis offered support for this supposition; across all 14 schools, elementary school staff were more likely to seek out advice about literacy compared with mathematics and science. Further, they were more likely to seek out others for advice related to teaching mathematics than science. Whereas staff members across the district’s schools nominated an average of three to four staff members as individuals they went to for advice about literacy, they nominated an average of two to three individuals in mathematics and one to two individuals in science (see table 2). At the school level, out-degree centrality in literacy ranged from 2.6 to 4.6, compared to a range of 1.6–3.1 in mathematics and 0.8–2.1 in science. At Kingsley, the average out-degree among school staff was 3.4 in literacy, 2.4 in mathematics and 1.3 in science.

Overall, the difference in average out-degree centrality between literacy and mathematics was over 50% across the district, and the difference between math and science was over 70% (see table 2). There was considerable variation between schools, where differences between literacy and math ranged from 8 to 109%, and from 4 to 188% between mathematics and science. We consider reasons for these between-school differences in the next two sections related to organizational infrastructure.

In addition to being more likely to seek advice about literacy than mathematics or science, elementary school staff in the Auburn Park school district were more likely to *provide* advice about literacy teaching than about math or science teaching. Average in-degree centrality measures across the district indicated that, while school staff members provided advice about teaching literacy to an average of three colleagues, they gave advice about math to an average of two others and about science to one other colleague (see table 2). Staff in-degree at Kingsley, for example, averaged 3.1 in literacy, 2.2 in math and 1.3 in science. Across schools, in-degree centrality varied from 1.9 to 3.7 in literacy, from 1.2 to 2.6 in math and from 0.7 to 1.9 in science. Even so, the difference in average in-degree centrality between literacy and mathematics was approximately 45% across schools, ranging from a difference of 4 to 98% (see table 2). Comparing mathematics and science, the difference in average in-degree between these two subjects was 70%, ranging from 17 to 154%.

Another important dimension of social networks is brokering, which we measure using betweenness centrality. Brokers are individuals who connect other actors in the network with one another and therefore occupy more prominent network positions. For example, while a particular staff member may lack the advice sought by a peer, she may know someone who would be a good source of this advice and may connect the colleague seeking advice from her with another colleague who she believes has the requested advice. At Kingsley, we noted above that a first-grade teacher served as a broker of math advice between the primary and upper elementary grades through her interactions with a third-grade and a sixth-grade teacher (see math network in figure 1). This type of brokering matters at Kingsley for the sharing of information about teaching and learning, given differences in the subject matter expertise between the lower and upper grade levels, as noted by the school principal: 'In the primary grades it's probably not really hard to find strong language arts people. In the upper grades it's a little harder to find reading teachers;

Table 2. Average centrality measures in subject matter networks, 2012.

	Literacy	Mathematics	Science	Change from math to literacy (%)	Change from science to math (%)
In-degree	2.93	2.02	1.19	+45.0	+69.7
Out-degree	3.63	2.41	1.40	+50.6	+72.1
Betweenness	38.08	21.94	2.52	+73.6	+770.6

you might find more math expertise there'. Thus, brokers at Kingsley were important for distributing subject matter expertise among teachers at all grade levels. Still, the brokering of teaching advice at Kingsley tended to be low overall, with slightly more brokering occurring in the literacy network; school staff members had an average betweenness centrality of 18.2 in literacy, compared to 15.3 in math and 1.8 in science.

Our overall analysis also reflected these differences between the school subjects, where, on average, there was more brokering of advice related to teaching literacy than advice related to teaching mathematics or science. Specifically, the average betweenness centrality for literacy in the Auburn Park school district was 38.1, meaning that each staff member linked two distinct staff members about 38 times. Betweenness in literacy networks ranged from 7.5 to 61.0 across the 14 schools. For mathematics networks, the average betweenness centrality for school staff was 21.9, ranging from 4.9 to 63.6. In science, brokering of advice was minimal overall, ranging from just 0.2 to 8.7 in the district's 14 elementary schools.

Still, the propensity of elementary teachers and school leaders to seek out, give, or broker teaching advice is also likely a function of the availability of individuals *designated* to provide advice as well as an individual's *willingness or ability* to provide such advice. Separating the two is difficult. Our analysis revealed that the distribution of advice giving across staff members also differed depending on the school subject. Overall, school literacy networks in Auburn Park were more equally distributed than school math or science networks. The average gini coefficient for literacy was 0.542, compared to 0.689 for mathematics and 0.797 for science, representing a 20% decrease in network equality from literacy to math, and a 13% decrease from math to science. These differences suggest that literacy networks included a greater number of individuals serving as central advice givers, whereas advice giving in mathematics and science was more centralized, or localized within fewer staff members. Our analysis suggests that literacy networks included more advice interactions and had more equal distribution of advice giving across staff members than mathematics and science. We next turn to examining these advice patterns in relation to the system and organizational infrastructure for supporting teaching in these three subjects.

Infrastructure, instructional interactions and school subject matters

Our account to this point has focused on subject matter differences in interaction patterns about teaching and learning in Auburn Park's elementary schools. Prior work suggests that these patterns are in part a function of the different subject matter norms and cognitive scripts that shape school and classroom practice around instruction (Spillane 2004, Spillane and Burch 2006, Stodolsky 1988). For one, teachers' conversations related to mathematics instruction often tend to focus on practical matters, skill mastery and student test scores, whereas discussions about literacy instruction tend to be more extensive in scope and include teaching philosophies and pedagogical approaches (Hayton and Spillane 2008).

Moreover, while teachers often take responsibility for leadership in school literacy instruction, they rely on formal leaders or outside experts to guide instruction in mathematics (Spillane 2005). At the same time, there is evidence that these cognitive and normative differences are reflected in the formal system and organizational structure or infrastructure including formal positions, organizational routines and so on. Prior work suggests that the infrastructure for supporting teaching and its improvement differs by school subject, with more formally designated leadership positions or specialists assigned to literacy than mathematics and fewer still to science (Hayton and Spillane 2008, Price and Ball 1997, Spillane and Burch 2003). Further, school administrators with no subject-specific leadership position were more likely to participate in organizational routines related to literacy than mathematics (Burch and Spillane 2003, Spillane 2005). These differences between school subjects are also evident at the institutional level; content standards and assessments were developed in literacy and math well before science or social studies (Burch and Spillane 2005).

We examined these trends with respect to Auburn Park's elementary schools. Our analysis suggests that Auburn Park's infrastructure for supporting instruction differed by school subject, especially in terms of the formally designated leadership and specialist positions assigned to particular school subjects. Our analysis also suggests that school leaders with no particular subject assignment were more central in some subject advice networks than others.

Each of the 14 elementary schools in Auburn Park had a full-time literacy facilitator, and five schools had reading specialists. In contrast, there were no building-based mathematics facilitators prior to 2011, when these positions were added in just two elementary buildings. Our analysis shows that formally designated school leaders and specialists with subject-specific positions were the most central advice givers and seekers in that subject area. Literacy facilitators, for example, occupied the most central positions in the literacy networks though not, as might be expected, in the mathematics or science networks (see table 3). Literacy facilitators were the most prominent advice seekers and providers, as well as brokers of advice, in school literacy networks. On average, 16 staff members nominated the literacy facilitator at their school as someone they went to for advice about teaching literacy. This figure ranged from 7–22 for the 14 literacy facilitators in the district. In addition to serving as central advice givers, literacy facilitators reported seeking advice about literacy from between 3 and 11 staff members, for an average out-degree centrality of 6. With respect to brokering, literacy facilitators brokered literacy advice between an average of 215 distinct pairs of staff members, ranging from 62 to 565 depending on the school. Each of the average centrality measures for literacy facilitators was significantly higher than the averages for classroom teachers, teacher leaders, reading specialists and school principals. For example, literacy facilitators were sought out for literacy-related advice eight times as much as teachers, five times as much as teacher leaders and over twice as much as reading specialists and school principals (see table 3).

Table 3. Mean (and Standard Deviation) comparisons for centrality measures, 2012, Based on one-way analysis of variances, with permutation-based standard errors and tests ($n = 371$).

	n	Literacy			Mathematics			Science		
		In-deg.	Out-deg.	Between	In-deg.	Out-deg.	Between	In-deg.	Out-deg.	Between
Principals	14	5.7 (3.3)	4.9(3.6)	137.4(65.8)	4.1(3.3)	3.6(2.9)	53.7(52.1)	1.7(1.8)	1.8(2.3)	10.0(18.6)
Literacy Facilitators	14	16.1 (4.7)	5.9(3.2)	214.9(177.2)	0.7(0.8)	1.1(1.1)	2.7(10.0)	1.1(0.9)	1.0(1.8)	0.0(0.0)
Reading Specialists	6	5.8(3.2)	6.3(4.0)	140.9(93.7)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)
Math Facilitators	2	1.5(0.7)	1.5(0.7)	3.8(5.4)	19.5(0.7)	8.5(4.9)	285.0(249.0)	0.5(0.7)	0.0(0.0)	1.57(5.9)
Teacher Leaders	96	2.8(1.7)	3.1(1.9)	31.3(44.9)	2.6(2.6)	2.4(1.8)	28.5(62.6)	1.5(1.2)	1.3(1.5)	3.3(8.1)
Teachers	239	2.0(1.4)	3.6(2.4)	22.4(39.4)	1.6(1.2)	2.4(1.9)	16.9(37.5)	1.1(0.9)	1.5(1.5)	1.9(5.4)
F		164.3	5.9	38.5	50.6	8.4	15.5	7.4	1.7	4.0
d.f.		5	5	5	5	5	5	5	5	5
p		0.0002	0.0002	0.0002	0.0002	0.0004	0.0006	0.0002	0.1248	0.0224

Note. Random replications are applied because our observations are not independent. Tests of significance are based on 5000 permutations.

In literacy, there were also six reading specialists in five of the district's elementary schools, yet no comparable positions existed for mathematics or science. These reading specialists were central actors in their schools' literacy networks, second only to literacy facilitators and on par with school principals (see table 3). Reading specialists provided literacy-related advice to an average of six colleagues, and they sought out an average of six colleagues for advice about literacy. They also brokered advice about literacy between an average of 141 pairs of colleagues. In contrast with literacy facilitators, who also participated in school math and science networks, albeit to a very limited extent, reading specialists were only present in school literacy networks, as evidenced in average centrality scores of zero in mathematics and science.

Just as literacy facilitators and reading specialists were the most central actors in school literacy networks, mathematics facilitators were the most central actors in school math networks. In the two schools where they were present, math facilitators provided advice to five times as many staff members as school principals, nearly seven times as many as teacher leaders and almost 10 times as many as classroom teachers (see table 3). Math facilitators also sought the most advice related to teaching math, with an average out-degree centrality of nine compared to four for principals and two for teacher leaders and teachers. Moreover, they served as the most frequent brokers of advice related to mathematics, brokering advice between as many as 285 distinct pairs of colleagues at their schools.

Although literacy facilitators, reading specialists and math facilitators were the most prominent actors in their schools' subject-specific advice networks, school principals and teacher leaders with no subject-specific leadership designations often occupied central positions in school literacy, mathematics and science networks. Consistent with prior work (Spillane and Kim 2012, Spillane *et al.* 2012), our analysis found that both principals and teacher leaders had significantly higher in-degrees than classroom teachers with no leadership positions in all three subjects (see table 3). Principals provided advice to an average of six staff members related to literacy, compared to four staff members in math and two staff members in science. Teacher leaders provided literacy advice to three colleagues, and provided math advice to two colleagues and science advice to one colleague. Principals in particular were also important brokers of advice about teaching literacy, mathematics and science. In literacy, principals brokered advice between an average of 137 distinct pairs of staff members, and between 54 staff members in math and 10 in science.

Even more striking, school principals and teacher leaders with non-subject specific leadership positions were more central in school literacy networks than in either mathematics or science networks. Further, they were more central in their schools' mathematics networks compared with their schools' science networks. Differences in in-degree, out-degree and betweenness for principals and teacher leaders were marginally significant between literacy and math and between math and science, and significant between literacy and science. Still, while principals and teacher leaders were most central in school literacy networks compared to math

and science, they were more central in school science networks than other leaders, suggesting that in the absence of subject-specific leaders, these other formal leaders picked up the slack in science.

Using the Kingsley case (see figure 1), we see that the literacy facilitator had the largest number of ties and was the most central actor in the school literacy network. Additionally, the school principal and a handful of other teachers, many of whom were teacher leaders, were also central in the network, but not nearly as central as the literacy facilitator. These trends are also evident in the literacy network of the second case school, Chamberlain Elementary (see figure 2). The prominence of the literacy facilitator can be attributed, in part, to the key roles they played in school organizational routines, specifically teachers' professional learning communities (PLCs), or grade-level teams. At Kingsley, and all Auburn Park elementary schools, teachers met weekly with their grade-level teams to discuss issues related to teaching and learning. Although these meetings were not intended to focus on a particular subject, literacy facilitators were always present, as William at Kingsley described: 'Our literacy facilitator, she was there [at the PLC meeting] every week. Usually [the meeting] included just our teaching team, literacy facilitator, and a special education teacher who was there most of the time too'. In having representation in weekly meetings for all teachers, literacy facilitators had a strong presence and were regularly involved in instructional decision-making at every grade level.

At Kingsley, where there was no mathematics facilitator present among the school staff, it is much more difficult to locate central advice givers in the math network compared to the literacy network; in science, it is even more difficult still (see figure 1). In contrast, at Chamberlain, where a mathematics facilitator joined the school staff in 2011, the prominence of this individual in the 2012 math network is evident (see figure 2). Moreover, Chamberlain's mathematics facilitator occupied a central role in the school's math advice network that closely approximated the centrality of the literacy facilitator in the school's literacy network. Still, the science networks at Kingsley and Chamberlain were similar, with no central actors present in that subject network at either school.

Changing organizational infrastructure, changing instructional advice interactions?

To further test our working assertions about the relations between organizational infrastructure and differences in advice interactions about teaching in particular school subjects, we examined how infrastructural changes contributed to changes in advice interaction patterns. Specifically, we examined whether and how the creation of math facilitator positions was associated with shifts in the instructional advice interaction patterns about mathematics. Did the addition of mathematics facilitators influence instructional advice interaction patterns in mathematics? Our analysis in this section focuses on two of our 14 elementary schools, Kingsley, where there was no math facilitator, and Chamberlain, where a full-time math

facilitator position was created in 2011. We examine changes between the 2010 and 2012 school years, using both network- and individual-level measures for literacy and mathematics (see table 4). (Data on science advice networks were not collected in 2010; thus, we cannot explore changes over time in that subject).

At Chamberlain, differences in staff advice interactions related to teaching literacy and mathematics diminished over time. The difference in network density between literacy and mathematics was 40% at Chamberlain in 2010, and decreased to a difference of just 8% in 2012, after the creation of the math facilitator position. Comparing figures 2 and 3, we get a more concrete sense of these shifts. Figure 3 shows Chamberlain's literacy and mathematics networks in 2010, before the math facilitator was included in the school organization. Here, the math network is much less dense, with less overall activity as compared to the network in 2012 in figure 2. At Kingsley, the differences in network density between literacy and mathematics decreased as well, but remained high, from 73% in 2010 to 52% 2012 (see table 4).

A similar trend was evident when examining the distribution of advice giving among school staff, with the number of central advice givers in literacy and mathematics reaching parity at Chamberlain in 2012 (from a difference of 10% to just 3% in the gini coefficients between literacy and mathematics). In contrast, the difference in network equality between literacy and mathematics widened over time at Kingsley, with advice giving in the school literacy network becoming more equally distributed among more staff members (i.e. with a gini coefficient of 0.614 in 2010 to 0.482 in 2012), and advice giving in the school math network becoming less equally distributed (i.e. with a gini coefficient of 0.784 in 2010 to 0.815 in 2012).

Several staff members at Chamberlain described these changes in their school mathematics network. In 2011, just after the mathematics facilitator position was instituted, Jillian, the school principal, commented that

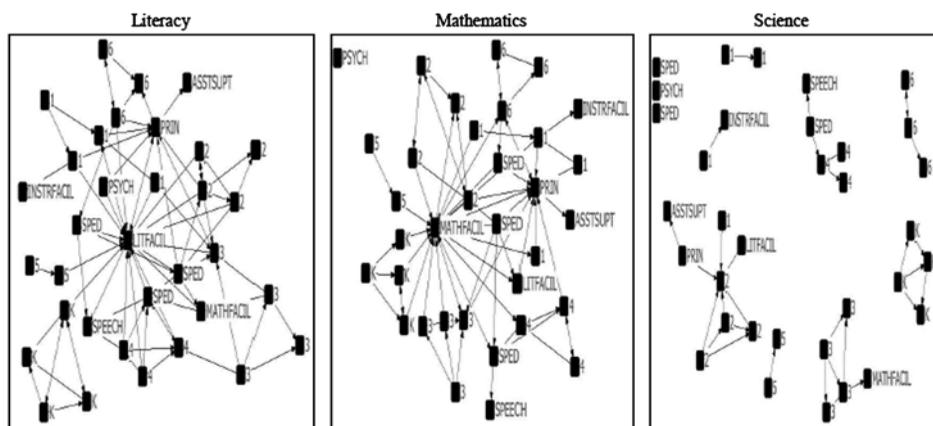


Figure 2. Chamberlain elementary school (with mathematics facilitator) social network diagram by subject, 2012.

Table 4. Social network measures for case study schools, 2010 and 2012.

	Kingsley (no facilitator)						Chamberlain (facilitator)					
	2010			2012			2010			2012		
	Lit.	Math	Change from math to literacy (%)	Lit.	Math	Change from math to literacy (%)	Lit.	Math	Change from math to literacy (%)	Lit.	Math	Change from math to literacy (%)
Density	0.104	0.060	+73	0.094	0.062	+52	0.077	0.055	+40	0.077	0.071	+8%
Gini	0.614	0.784	-22	0.482	0.815	-41	0.701	0.780	-10	0.549	0.566	-3%
In-degree	3.43	2.05	+67	3.09	2.19	+41	2.73	1.73	+58	2.67	2.57	+4%
Out-degree	3.86	2.24	+72	3.44	2.38	+45	3.21	1.91	+68	3.10	2.87	+8%
Triads (open and closed)	674	181	+272	447	111	+303	306	171	+79	342	316	+8

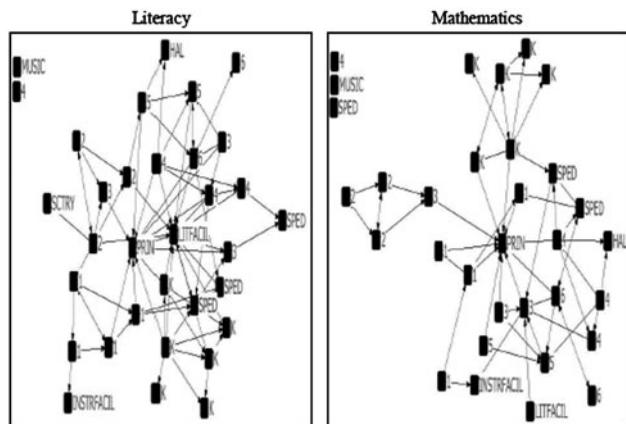


Figure 3. Chamberlain elementary school (prior to mathematics facilitator) social network diagrams by subject, 2010.

teachers were beginning to talk much more about mathematics: ‘The teachers interact a lot about language arts, about guided reading and writer’s workshop, but we’re beginning to have more conversations about math, and in a new and different way’. Jodie, a special education teacher at Chamberlain, also captured this shift noting that, ‘I think in this district there’s been so much that had always been literacy, literacy, literacy, and even the past few years I was like, ‘Okay but what about math?’ Now, you can see that math is slowly becoming equal to literacy’. Our analysis suggests that the creation of a formal full-time leadership position designated to mathematics promoted school-wide interactions about mathematics that in turn contributed, somewhat counterintuitively, to a more equal distribution of advice giving about mathematics across school staff at Chamberlain.

Indeed, over time there was an increase in advice interactions about mathematics at Chamberlain that was not evident at Kingsley. At Chamberlain, the average staff out-degree in mathematics increased from 1.91 in 2010 to 2.87 in 2012, indicating that staff members on average sought out an additional person for advice related to mathematics. This increase meant that advice seeking in mathematics became nearly the same as advice seeking in literacy at Chamberlain, whereas at Kingsley, differences in advice seeking between the two subjects remained. Similarly, the level of advice providing related to mathematics increased at Chamberlain over time, where school staff nominated an average of 1.73 colleagues as individuals they went to for advice about math in 2010, compared to 2.57 individuals in 2012. At Kingsley, advice providing remained about the same, with staff nominating an average of 2.05 colleagues in 2010 and 2.19 in 2012.

Another shift in Chamberlain’s mathematics network after the creation of the math facilitator position was in triadic relationships among school staff. Triadic relationships, or instances where three staff members are tied to each other in a network, are considered the smallest social

structure that has the character of a society and where tendencies such as equilibrium, constancy and hierarchy (key markers of institutionalization) emerge (Heider 1958, Madhavan *et al.* 2004, Simmel 1950). In this way, triadic relationships are especially important for social influence. In 2010, there were 306 triadic relations (both open and closed triads) in Chamberlain's literacy network, which increased slightly to 342 in 2012. In Chamberlain's mathematics network, the number of triads increased from 171 in 2010 to a full 316 in 2012, greatly reducing the difference between literacy and mathematics in the presence of triadic relations. Focusing on the school mathematics facilitator, when she was a full-time classroom teacher in 2010, she was part of 28 triadic relationships among school staff (24 open and 4 closed); in 2012, she was part of 190 triads (170 open and 20 closed). Thus, she helped form 16% of Chamberlain's triadic relationships in 2010, compared to 60% of these relations in 2012. These increases in triadic relationships that paralleled the level of triadic relationships in literacy provides further evidence that the creation of a subject-specific leadership position for mathematics facilitated interactions and promoted overall network activity in that subject.

Discussion and conclusion

Our analysis supports and extends earlier theory-building work in at least three ways. First, we show that elementary school staff members organize for instruction differently depending on the school subject. Specifically, our analysis is consistent with earlier work that shows that elementary school staff are more likely to seek advice about literacy compared with both mathematics and science, and with mathematics compared with science. School staff are also more likely to provide and broker advice about teaching literacy compared to mathematics and science. Moreover, school literacy advice networks are more likely to have an equitable distribution of advice giving, with greater numbers of central advice givers present in literacy networks than mathematics or science networks, and greater numbers of central advice givers in math networks compared to science.

Second, our analysis offers support for the hypothesis that these subject matter differences in elementary school instructional advice interactions are related to subject-specific differences in the organizational infrastructures that support teaching and efforts to improve teaching. Specifically, organizational infrastructures differed depending on the school subject, where there were more subject-specific leaders and specialists assigned to literacy than either mathematics or science, and more leaders assigned to mathematics than science. These formally designated leaders were central advice and information providers and brokers, but only within teaching advice networks related to the school subject to which they were assigned. Moreover, the roles that school principals and other non-subject-specific leaders played varied depending on the school subject, and they were more prominent in literacy networks than in mathematics or science networks. Still, in the absence of subject-specific

leaders in science, these formal leaders were more central in science networks than other staff members, suggesting that even the non-subject-specific infrastructure was important in shaping interactions about teaching among school staff. Thus, overall, our analysis shows that the design of the formal organizational infrastructure is an important consideration in teaching and learning reform, but these infrastructures play out differently across the school subjects.

Third, in addition to demonstrating that the subject matters in terms of staff interactions and school system infrastructure, we capitalized on our longitudinal data and showed how infrastructural changes can work to ameliorate subject-specific differences in staff interactions about teaching. Specifically, the creation of mathematics facilitators in two of the district's schools contributed to substantial changes in those schools' staff advice networks related to teaching mathematics. These differences, in turn, contributed to reducing the differences between literacy and mathematics teaching advice networks. Schools with mathematics facilitators achieved levels of advice seeking, giving and brokering in mathematics that became more similar to levels of advice seeking, giving and brokering in literacy. Further, these changes in advice interactions about mathematics in schools where facilitators were introduced were not evidenced in those schools where mathematics facilitators were not present.

Our analysis, then, reveals that how schools organize for instruction differs depending on the school subject and offers evidence to suggest that such differences in school staff instructional advice interaction patterns are tied to differences in the organizational infrastructure designed to support instruction in literacy, mathematics and science. Given that teachers' on-the-job interactions are vehicles for learning (Eraut 2004, Eraut and Hirsh, 2007, Frank *et al.* 2004), these differences in how schools organize teaching in core school subjects are consequential for teachers' opportunities to learn from one another. In particular, our analysis showed that teachers' opportunities to learn are substantially greater in literacy than in mathematics or science. Since teacher learning is essential for instructional improvement (Darling-Hammond *et al.* 2009, Elmore 1996, Hill 2004), then our findings suggest that schools have the most potential to improve teaching in literacy, and that improvements to teaching in mathematics—and even more so in science—may be difficult, especially within current school system infrastructures.

These findings have important implications for policy and practice, particularly in light of efforts currently underway in the USA to define new and more ambitious core learning standards for literacy, mathematics and science (National Academy of Sciences, Achieve, American Association for the Advancement of Science and National Science Teachers Association 2013, National Governors Association Center for Best Practices and Council of Chief State School Officers 2010a, 2010b). As several scholars have pointed out, teacher learning will be essential for the successful implementation of the sort of intellectually rigorous instruction advanced by these standards (Cohen and Barnes 1993, Schifter 1996). Our account suggests that these instructional policy initiatives will face distinctly different implementation challenges in local school systems and

schools depending on the subject. As such, policy-makers and practitioners alike should think carefully about how to design infrastructures that support interactions among school staff, thereby fostering learning, and how these infrastructures cater to teacher's learning needs in particular subject areas. Moreover, our account suggests that, when doing comparative work in education, there is a need to consider how education systems in different parts of the world are similar and different, especially with respect to the system and school organizational infrastructures for supporting teaching and efforts to improve it in particular school subjects.

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Note

1. Given the relative similarity in network size across schools, we present unstandardized measures in this paper so that the data could be interpreted more meaningfully. Our analysis of the standardized measures showed slightly larger differences between groups; thus, our presentation of the unstandardized measures does not overreport our findings.

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