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The Embeddedness of Teachers' Social Networks: Evidence from a Study of Mathematics Reform

Cynthia E. Coburn[1], Willow S. Mata[2], and Linda Choi[2]

Abstract

Teachers' social networks can play an important role in teacher learning and organizational change. But what influences teachers' networks? Why do some teachers have networks that are likely to support individual and organizational change, while others do not? This study is a first step in answering this question. We focus on how district policy influences the quality and configuration of teachers' social networks. We draw on a longitudinal, qualitative study of implementation of a mathematics curriculum in four schools. We show that district policy (1) shaped the tie formation process, influencing the structure of networks; (2) mobilized resources that teachers subsequently accessed via their networks, influencing the benefits accrued through network exchanges; and (3) introduced interaction routines that interrupted conventional ways that teachers talked together. We thus uncover heretofore unexplored facets of network formation and change. We also provide insight into dimensions of social networks that are amenable to outside intervention.

Keywords

Social networks, embeddedness, teachers, implementation

Since the standards movement in the 1990s, there has been increased attention on the role of teacher learning in educational improvement efforts. Districts across the United States have developed more systematic approaches to teacher learning: They have invested increased resources in teacher professional development, convening teachers at schools or across the district to work together to learn new instructional approaches (Desimone 2010; Elmore and Burney 1999; Gamoran et al. 2003). Districts have hired instructional coaches to work with individuals or teams of teachers at the school site to encourage them to make changes in their practice (Bean 2004; Coburn and Woulfin 2012). And, based on the theory that teachers learn best through social interaction, many districts have instituted professional learning communities. Creating time and space for teachers to meet, the logic goes, provides opportunities for teachers to learn from one another as they grapple with new instructional approaches (Grossman, Wineberg, and Woolworth 2001; McLaughlin and Talbert 2006).

These strategies all emphasize leveraging the power of teachers' social and professional

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relationships to encourage instructional improvement and organizational change. Indeed, existing research provides evidence that teachers' social relations can play an important role in these outcomes. Sociologists of education have found that social networks with particular qualities—for example, tie strength, depth of interaction, or expertise—are associated with reform implementation (Frank, Zhao, and Borman 2004; Penuel, Frank, and Krause 2010), innovative climate (Moolenaar and Sleegers 2010), sustainability (Coburn et al. 2012), and student learning (Yasumoto, Uekawa, and Bidwell 2001). Research on teachers' professional communities suggests that teachers in schools with strong professional communities are more likely to make changes in their practice (Elmore, Peterson, and McCarthey 1996; Louis and Marks 1998; Newmann, King, and Youngs 2000) and produce increases in student learning (Bryk et al. 2010; Rosenholtz 1991; Yasumoto et al. 2001) than teachers without these social supports. These studies provide evidence that the structure of social relations has consequences for public school performance and the prospects of organizational change.

However, while sociologists of education have highlighted the important role of teachers' social relations, research has provided less insight into why some social networks are configured in ways likely to foster instructional improvement while others are not. Policy makers and leaders are increasingly creating initiatives with the express purpose of altering the ways teachers interact to foster learning. Yet we know little about how the policy context of public schools influences how teachers' social networks form, function, or change over time.

Sociologists of education are not alone in their limited attention to the role of context in social networks. Social network researchers have typically emphasized the emergent and informal qualities of networks and their abilities to transcend organizational boundaries. Researchers have paid less attention to the role of formal bureaucratic mechanisms such as policy in influencing informal social relations. Thus, we know little about how social networks are embedded in the broader organizational and policy context (Adler and Kwon 2002; Borgatti and Foster 2003; Small 2009).

We address this limitation. We draw on data from a longitudinal study of the district-wide implementation of an innovative elementary mathematics curriculum to investigate how social policy penetrates the organizational boundaries of schools to influence teachers' social networks. During the three years of our study, the district in question underwent significant policy changes related to mathematics instruction. These shifts provided an opportunity to see macro–micro relationships—in this case, the relationship between policy and social networks—that are difficult to see during periods of stability or incremental change.

Our exploratory study shows that district mathematics policy influenced teachers' social networks in three ways. It influenced the tie formation process, shaping the structure of teachers' networks. It mobilized significant resources that teachers subsequently accessed via their networks, influencing the potential benefits that teachers accrued through network exchanges. And, district policy introduced new forms of interaction that shaped the nature and content of teacher talk in teachers' networks.

This study contributes to our understanding of the intersection between social networks and organizational change by uncovering the ways that teachers' social networks are embedded in and affected by social policy. This understanding may prove important for explaining why some teachers have networks that support instructional improvement, while others do not. This study also contributes to social network research more broadly by extending our understanding of the tie formation process, elucidating when and how the mechanisms for tie formation change in response to environmental conditions. It also shines a light on the content of social network transactions, providing insight into what actually flows along networks, when, and why. Finally, we provide new understanding of the dimensions of social networks that are amenable to outside intervention, uncovering points of leverage for encouraging network development and sustainability in schools.

LITERATURE REVIEW

The concept of embeddedness has played an important role in scholarship on social networks for some time (Kilduff and Brass 2010). *Embeddedness* refers to the idea that individual action is situated within and shaped by a network of social relations. As Granovetter (1985:487) explains in his seminal article,

> Actors do not behave or decide as atoms outside a social context, nor do they adhere slavishly to a script written for them by the particular intersection of social categories that they happen to occupy. Their attempts at purposive action are instead embedded in concrete, ongoing systems of social relations.

Embeddedness can be structural, as when individuals are located in dyadic relationships, which themselves are located in a web of direct and indirect ties (Borgatti and Foster 2003; Granovetter 1985). It can also be historical; any given interaction is conditioned by the social interaction that came before (Granovetter 1985; Kilduff and Brass 2010). The concept of embeddedness has inspired a generation of researchers who have applied the concept to a wide range of settings, including economic activity, schools, health and human services, and neighborhoods.

However, much of this research has paid little attention to how networks themselves are embedded in a larger context (Adler and Kwon 2002; Small 2009). Social network researchers typically view network formation as an emergent process, arguing that networks form as individuals opt into relationships with one another. There is comparatively little attention to the way that the environment might influence this process, leading researchers like Borgatti and Foster (2003) to call for greater attention to the organizational antecedents of network formation and Small (2009) to call for a theory of organizational embeddedness.

A theory of organizational embeddedness may be especially important for understanding social networks in public schools. Public schools are highly bureaucratized, with a multilevel and multidivisional structure that likely influences interaction patterns (Adler and Kwon 2002; Coburn and Talbert 2006). Public schools are also situated in complex policy and institutional environments that are increasingly likely to penetrate the technical core of schooling to influence teachers' work (Anagnostopoulos 2003; Coburn 2004; Diamond 2007) and social interaction (Coburn and Russell 2008; Spillane, Parise, and Sherer 2011).

While there is little research that investigates the role of policy context in social networks, there is some research that attends to organizational context. This work provides hints about how teachers' social networks might be embedded in and affected by policy. It suggests that policy may influence three dimensions of teachers' social networks: (1) tie formation and maintenance, (2) the nature of resources that flow along the ties, and (3) the content of social network transactions.

Tie Formation and Maintenance

Scholars have noted that organizational structure (e.g., configuration of roles and subunits) shapes patterns of interaction, which fosters development of some ties and discourages others (Adler and Kwon 2002; Small 2009). Researchers posit a number of mechanisms for this influence. First, organizations may foster tie formation via the configuration of time and space. We know that individuals are more likely to form ties with people when they trust or feel close to those people (Borgatti and Foster 2003; Granovetter 1985). This may be especially true for teachers. Sociologists of education have long argued that teaching is an uncertain and complex task. Yet occupational norms of privacy work against teachers seeking out others to help navigate this complexity (Lortie 1975). In this environment, seeking out others to talk about teaching and learning involves considerable risk: risk of violating norms, risk of exposing teaching problems (Little 1990). These risks may be magnified when teachers take on new instructional approaches that require them to try new techniques or challenge them to increase their subject matter knowledge (Bryk and Schneider 2002).

We know that frequent interaction fosters trust and social closeness (Rivera, Soderstrom, and Uzzi 2010; Uzzi and Lancaster 2004). Thus, schools and districts may foster tie formation directly by creating activities like meetings or professional development that bring teachers together in frequent and sustained ways (Gamoran, Gunter, and Williams 2005; Jennings 2010). Districts may also foster tie formation indirectly by arranging physical space such that teachers interact with some colleagues with greater frequency than others by virtue of proximity. For example, public schools regularly assign teachers of similar grade level and subject matter departments to contiguous physical space. Some schools and districts also provide opportunities for teachers to meet with their grade level or, in secondary schools, subject matter department colleagues. Perhaps for this reason, grade level in elementary school and subject department in high school are important predictors

of social ties (Bidwell and Yasumoto 1999; Penuel et al. 2010).

Second, organizations may influence tie formation as they structure work practices and roles (Brass, Forthcoming). Homophily—the principle that people are more likely to make contact with others that are similar to them—is a key predictor of tie formation and maintenance. Individuals seek out others whom they see as like themselves because they assume these others are trustworthy and hold similar beliefs. Individuals also assume that relationships with others like themselves are less likely to involve conflict and more likely to involve shared language (Borgatti and Foster 2003; McPherson, Smith-Lovin, and Cook 2001).

Schools and districts can influence whom one sees as similar in the way they structure work roles. Schools organize teachers by grade level, subject matter, or specialized roles (e.g., special education teacher, reading coach). These organizational structures may shape how teachers see themselves and thus whom they see as being like themselves (Coburn, Choi, and Mata 2010). In this way, organizational context may influence who teachers go to when they seek out others like themselves.

Third, organizations may also influence tie formation through the creation of a common focus. At a minimum, a common focus gives individuals something to talk about (Small 2009). It may also foster positive sentiment and cultural norms of sociability and may serve to emphasize shared interests rather than discordant ones, increasing the propensity of teachers to form relationships (Feld 1981; Rivera et al. 2010). By creating a common focus, the introduction of an instructional reform may make it more likely that teachers break through occupational norms of privacy to seek out others with whom to discuss instruction.

Providing Resources

Organizations may also influence the resources that flow along ties. Researchers argue that social network outcomes derive from the ability of individuals to gain access to valued resources by virtue of their location in a network (Adler and Kwon 2002; Lin 2001). These resources can include information, material goods, or services (Small 2006, 2009) as well as expertise (Adler and Kwon 2002). However, social networks can vary greatly in the level and kind of resources that are available within them (Small 2006). For example, in our earlier work, we showed that teachers' networks varied greatly in the degree to which they provided access to colleagues with mathematics expertise (Coburn and Russell 2008; Coburn et al. 2012).

There are reasons to believe that the organizational and policy context can influence the resources that are available in networks. Schools routinely provide professional development intended to increase teachers' expertise. Theoretically, if a school or district increases its staff's level of expertise by providing professional development, the likelihood that teachers will encounter more expert colleagues when they seek advice also increases.

Similarly, schools and other organizations frequently provide material resources and information to their employees and clients. For example, Small (2009) shows that the child care centers in his study drew on interorganizational linkages to broker mothers' access to material goods, information, and referrals to outside services. This raises the possibility that individuals may have access to more, less, or different kinds of resources or information in their networks depending upon the resources an organization provides.

Content of Interaction

Finally, the organization and policy context may influence the content of interaction: how individuals interact with resources and each other during social network transactions. Occupational norms can influence the frequency and focus of interaction (Van Maanan and Barley 1984). In public schools, longstanding norms of privacy and autonomy tend to work against teachers sharing information related to teaching and learning, the problems teachers face, or joint work. Therefore, when teachers do interact, they tend to do so in relatively superficial ways: quick exchanges involving storytelling, limited assistance (only when asked), and exchange of materials, activities, or handouts (Little 1990; Lortie 1975). In recent years, however, schools and districts have attempted to interrupt these norms by fostering interaction focused on teaching and learning as part of professional learning community initiatives (Grossman et al. 2001; McLaughlin and Talbert 2006). There is evidence that some schools do develop local norms of inquiry or collaboration (Little 2007). Therefore, it seems possible that school or district initiatives

not only shape how often teachers interact but have the potential to shape the content of that interaction as well.

While existing research provides hints about the ways that social networks are embedded in larger social contexts, there is still much to learn. First, the small body of network research that attends to context focuses primarily on the role of the organization; there is almost no research on the role of social policy. Thus, we know little about how policy penetrates the organizational boundary of the school to influence tie formation, resource flows, and content of interaction in teachers' social networks. Second, research identifies a list of factors that predict tie formation and maintenance but provides little insight into how these factors interact with one another or shift over time. Third, social network research pays limited attention to the content of interaction; we know almost nothing about what actually happens in social network transactions, much less the role of social and organizational context in that interaction. Finally, we know virtually nothing about the impact of intentional efforts to alter teachers' social networks in public schools. This study takes up these issues.

METHODS

To investigate the relationship between social policy and teachers' social networks, we draw on data from a longitudinal study that focused on how district reform strategies interacted with human and social capital in the implementation of ambitious mathematics curricula in two school districts. For this article, we draw on data from one district for which we have complete social network data over the three years of the study. Greene School District[1] is a midsize urban district that adopted the innovative curriculum *Investigations in Data, Numbers, and Space* in the 2003–2004 school year, the first year of our study. The district also launched an initiative to support teachers in learning the new curriculum, including creating school-based instructional coaches and multiple opportunities for teachers to meet with others to talk about mathematics.

Sample

Consistent with the exploratory, theory-building purpose of our study, we used purposive sampling (Strauss and Corbin 1990) to select four elementary schools. Because the overall study was interested in how schools with contrasting organizational conditions—different levels of social and human capital—implemented the new mathematics curriculum, we sought four schools that varied along these two dimensions. We asked the district director of mathematics to nominate schools where the faculty had, on average, relatively high and low levels of human and social capital, with human capital described as math instructional expertise and social capital described as interaction about mathematics instruction. We confirmed these nominations with preliminary data collection at each school. The final sample included four contrasting organizational conditions: one school with a strong professional community and strong teacher expertise, one with a strong professional community and weak teacher expertise, one with a weak professional community and strong teacher expertise, and one with a weak professional community and weak teacher expertise.

Greene School District is located in an urban, southwestern community of mostly working-class, Spanish-speaking families. All four schools in the study had 70 percent or more of their students enrolled in free and reduced-price lunch programs at the start of the study, and 70 percent or more of their students were Latino, mostly of Mexican origin. About half of the students of all four schools were classified as English Language Learners (ELLs), a fact that became important in year 3 of the policy changes we studied.

We selected four focal teachers in three schools. In the fourth—school H—we were able to select only two focal teachers for logistical reasons. Teachers at all four schools were selected to represent a range of grades and attitudes toward the new curriculum. Two of the original 14 teachers left their schools during the three years of the study. Both were new teachers in year 1 and, like many new teachers (Johnson, Berg, and Donaldson 2005), decided to leave the profession after a few years. For this article, we included only the 12 teachers for whom we have three years of data. See the methodological appendix for more information on sampling, the schools, and the focal teachers.

Data Collection

We conducted two interviews and three classroom observations for each focal teacher in year 1. We expanded data collection in years 2 and 3, collecting five interviews and six classroom observations

per focal teacher. Each year, we interviewed each mathematics coach[2] and principal one or two times. We also interviewed each of six additional teachers per school (whom we called *nonfocal teachers*) once per year. Interview questions focused on opportunities to learn about the mathematics curriculum, to whom teachers turned for advice outside formal meetings, and the topics for which teachers sought advice from colleagues. Finally, in each school, we observed three to five occasions per year where teachers interacted about mathematics instruction: professional development, grade-level meetings, coaching sessions, and so on. We recorded and transcribed verbatim all interviews. We wrote up observations using ethnographic field notes that focused on who interacted with whom, about what, with what materials.

A subset of this data collection was designed to investigate focal teachers' social networks. We took an egocentric approach to social network analysis. Thus, we mapped networks that were centered around an individual or social unit (the *ego*) (Wellman and Berkowitz 1988). To construct egocentric networks, we interviewed each focal teacher using questions designed to find out whom the teacher sought out when she needed advice about mathematics instruction (teachers' outgoing ties).[3] We then asked questions about each person the focal teacher identified, including the frequency and content of interaction and why the teachers sought advice from some people and not others. We analyzed these data and selected six additional nonfocal teachers in each school who were part of focal teachers' networks. We then interviewed nonfocal teachers using the same social network questions supplemented with questions about the teachers' use of curriculum and their background in mathematics. This approach allowed us to investigate in more depth the nature of focal teachers' networks, including the location of expertise and content of interaction. We also devoted part of our interviews with coaches and principals to the same social network questions. We supplemented interviews by observing occasions on which focal teachers interacted with colleagues identified in their social network interviews. Finally, to understand the role of district policy in teachers' social networks, we conducted 17 interviews with 13 key district leaders, observed 20 professional development sessions for teachers and coaches, and collected and analyzed relevant district documents.

Data Analysis

We began data analysis at the policy level. We analyzed data from interviews, observations, and policy documents to construct a narrative of district policy over the three years of the study, paying attention to changes that affected teachers' opportunities to interact about mathematics. We tracked the changes in the mathematics initiative, producing matrices of changes in policy and district expectations for teachers.

Next, we mapped each of the 12 focal teachers' social networks for each of the three years. We then analyzed three dimensions of the structure of the networks: network size, diversity of ties, and access to expertise. To analyze size, we counted the number of nodes in each teacher's network that were one step away from a focal teacher in a given year. To analyze the diversity of ties, we analyzed the degree to which a teacher had ties that spanned different functional areas inside and outside the school (e.g., others in a focal teacher's grade level, in other grade levels, mathematics coaches, administrators, and those outside the school). We then calculated the percentage of ties to others in areas beyond a focal teacher's grade level. To analyze access to expertise, we created a metric to assess the degree to which individuals in a social network had expertise, defined as having participated in prior professional learning opportunities related to mathematics. We then analyzed the expertise of each person in a focal teacher's network (see Appendix A for definitions of *expertise*).

After we analyzed each teacher's social network, we investigated whether there were differences in networks by school. We found greater variability within schools than between schools on size, diversity, and access to expertise of teachers' social networks.[4] For this reason, we report patterns across our 12-teacher sample. We note in the text the few instances where there were differences by school.

Next, we investigated the relationship between networks and the district mathematics policy. We started by analyzing the information we gathered about why teachers formed ties to particular individuals in their network, investigating the degree to which aspects of policy played a role. We used a hybrid approach to coding (Miles and Huberman 1994). That is, we started with a priori codes suggested by existing research on tie formation (e.g., proximity, homophily, and prior

relationships) but then added additional codes that emerged inductively from the data, including expertise, reform activities, friendship, and shared values. (See Appendix A for definitions used in coding.) We then charted how teachers' reasons for forming ties changed each year. When it became clear that there were interesting patterns related to perceived expertise, we analyzed the actual expertise in teachers' networks using our metric. We then compared the ties that teachers formed because they saw individuals as having expertise with our assessment of their expertise, charting this relationship over time.

We analyzed the content of interaction: network flows and modes of interaction. Social network analysis typically focuses on the structure of ties, paying less attention to what flows across them (Borgatti and Ofem 2010) or the nature of social interaction therein (Coburn and Russell 2008). Because we combined interviews and observations with social network analysis, we were able to directly investigate what happened when teachers interacted with others. Drawing on interview and observational data, we identified 419 interactions that the 12 focal teachers had with others in their networks. An interaction included any occasion when teachers communicated with others in their networks that we observed or heard about from teachers. We compiled all the information on a given interaction from observations and interviews with multiple participants and then coded it in three ways: depth, the presence of routines of interaction, and resources.

We drew on our previous work (Coburn 2003) to develop criteria for depth of interaction. Interaction was judged to be at low depth when it focused on surface structures or procedures, such as sharing materials without discussion, classroom organization, pacing, or how to use the curriculum. Interaction was judged to be at high depth when it addressed underlying pedagogical principles of the approach, the nature of the mathematics, or how students learn. (See Appendix A for complete definitions of *depth*.)

While analyzing the interaction for depth, we noticed that many interactions followed a distinct and somewhat counter-normative turn; teachers appeared to be interacting with others in an extended and patterned fashion that departed significantly from accounts of teacher interaction in the existing research. We also noticed that these interactions resembled professional development we had seen district leaders undertake with coaches but never with teachers. To investigate the relationship between the professional development for mathematics coaches and the distinct forms of interaction that we saw in teachers' networks, we analyzed interviews, observations, and documents from the district level and inductively identified patterns of interaction present in district professional development with coaches. Following Feldman and Pentland (2003), we define these patterns as *routines*, or ''repetitive, recognizable patterns of interdependent actions, carried out by multiple actors'' (p. 95). In all, we identified eight district-designed ''routines of interaction'' intended to guide coaches in their conversations with teachers about instruction. (See Appendix A for a description of routines.) We then analyzed the 406 interactions in teachers' networks for which we had enough information to assess the presence of these district-designed routines. We investigated where in the networks the routines occurred (with grade-level colleagues, cross-grade colleagues, coaches, administrators, or those outside the school) in each year. We also analyzed the relationship between different routines of interaction and depth.

Finally, we coded each interaction for the nature of the resources that flowed during social network transactions. Small (2006) defines *resources* as ''any symbolic or material good beneficial to an individual'' (p. 276), including material resources, information, and services. Drawing on Small's conceptualization, we coded all interactions for the presence of information, materials, and services. (See Appendix A for definitions used for coding resources.) Using information from district interviews and the analysis of district policy documents, we then analyzed whether the resources, information, or services originated from the district or from some other source. Once coding was complete, we investigated patterns of change in type and volume of resources flowing across the three years. Because we found no instances where services (district or nondistrict) flowed across teachers' social networks, we dropped that category from our analysis.

RESULTS

Mathematics Reform in Greene School District

Across the three years of our study, Greene School District initiated and subsequently dismantled

a major reform initiative to support implementation of a new mathematics curriculum. Because the initiative had several features that specifically targeted teachers' social relations, the development and subsequent decline of the initiative provide an opportunity to investigate the role of policy context in the nature of teachers' social networks. We begin by providing an overview of changes in the mathematics initiative in Greene across the three years.

In year 1, the district adopted a new mathematics curriculum called *Investigations in Data, Numbers, and Space* and designed a series of activities to help teachers implement the curriculum. First, the district created the role of a school-based mathematics coach. Each school was to appoint a minimum of two half-time coaches/half-time teachers who worked with teachers. Second, the district instituted weekly grade-level meetings to facilitate joint planning and biweekly school-based professional development. A district-level team supported coaches, providing them with regular professional development and observing their work once a month. Third, the district provided professional development in the summer and intersession to select teachers. Thus, the district initiated multiple structures that required teachers to interact with new people in new ways around mathematics.

In year 2, the mathematics initiative accelerated. The district offered additional professional development to teachers in cross-district settings. The school-level professional development, instituted the year before, shifted to cross-grade-level configurations, enabling teachers to meet with those in other grades more often. Professional development also became more focused on substantive issues: how students learn, the nature of mathematics, and how to solve actual math problems. The district also continued to provide professional development to the on-site coaches, increasing their mathematics expertise.

In year 3, the district shifted its priorities and withdrew support for the reform. The initiative had become controversial, with some in the district arguing that the curriculum was not appropriate for English Language Learners (ELL students) because it was too language-intensive. The superintendent retired, and the new superintendent decided that the main priority for the district was going to be the education of ELL students. He decided to enforce a preexisting agreement with the Office of Civil Rights that required all teachers to teach 30 minutes a day of English Language Development (ELD) strategies. To make room for this time, he reduced mathematics instruction from 90 minutes a day to 60. The state also passed legislation requiring all teachers to have a ''Structured English Immersion Endorsement'' that required 15 hours of professional development on ELL strategies. To meet these demands, the district redirected its professional development resources toward ELL instruction.

The superintendent also rolled budget and staffing decisions to schools and ended the district stipend that teachers received if they took on coaching duties, leaving it up to schools to fund coaches. In response, principals in three of the four schools cut back to a single half-time coach. (The fourth school cut back to two coaches from three; however, the second coach left midyear to assume district responsibilities.) At the school level, principals also redirected professional development resources. The district's new emphasis and the need to provide professional development on ELL instruction so that teachers could meet their certification requirements meant that many of the structures that fostered interaction around mathematics were eliminated or greatly curtailed.

Greene Mathematics Policy and Teachers' Social Networks

These shifts in district policy had implications for the nature and configuration of teachers' social networks. They influenced the tie formation process, shaping the structure of teachers' networks. They also served to increase and then withdraw resources, which subsequently became available to teachers through their ties, shaping what flowed through network ties. And, these policy shifts influenced how teachers interacted with one another in their networks. Policy actions inadvertently promoted new modes of interaction, shaping how teachers talked with others in their network, what they talked about, and, thus, their potential for learning from one another.

Social Policy and Tie Formation: The Building Blocks of Social Networks. Existing research suggests that organizations influence tie formation through the configuration of time and space, the development of shared focus, and the construction of work roles (Rivera et al. 2010; Small 2009).

Table 1. Size and Diversity of Teachers' Networks over Time.

	Year 1	Year 2	Year 3
Average network size (number of nodes)	4	11	8
Average percentage of network from grade level	53%	46%	71%
Average percentage of network from different grade levels	10%	17%	10%
Average percentage of network who are coaches	28%	15%	14%
Average percentage of network who are administrators	4%	4%	1%
Average percentage of network from outside school	7%	14%	5%

Here, we argue that social policy can influence these conditions, shaping the process of tie formation as well. We provide evidence that by creating opportunities for teachers to meet regularly to talk about mathematics, the district facilitated the formation of ties and an expansion of teachers' social networks. The networks subsequently contracted when these supports were withdrawn. We also uncover an additional way that policy influenced tie formation: the provision of opportunities for teachers to learn where expertise about mathematics instruction was located. Teachers drew on this knowledge to become more strategic about who they sought out, even as networks contracted in year 3.

Opportunities to meet and network formation. The creation and subsequent dissolution of formal opportunities for teachers to meet played an important role in the configuration of teachers' social networks. In year 1, the district introduced a new set of structures for teachers to discuss mathematics. In year 2, the district reconfigured these structures so that teachers were more likely to work with those in other grades and more likely to focus on mathematics teaching and learning. The district then greatly reduced these opportunities for sustained interaction in year 3.

At the same time, there was a rapid expansion in the size and diversity of teachers' social networks from year 1 to 2 followed by a contraction in year 3. As you can see in Table 1, teachers' social networks were quite small in year 1, with an average of four others. Furthermore, they were heavily conditioned by grade level. Fifty-three percent of teachers' ties were to grade-level colleagues, and nearly half of teachers in our sample had social networks that were made up entirely of grade-level colleagues and coaches in year 1.

Teachers' mathematics networks changed dramatically from year 1 to 2. They increased in size from an average of 4 nodes to 11. They also became more diverse: grade-level colleagues declined to 46 percent of ties in year 2 as teachers' networks expanded to include a greater percentage of those in different grade levels and individuals outside their school.[5] However, in year 3, teachers' social networks contracted markedly. The average size of networks declined from 11 nodes in year 2 to 8 nodes in year 3. Network diversity also decreased, as teachers' networks once again became predominantly made up of grade-level colleagues.

Xandria, a first- and second-grade teacher in School F, illustrates this pattern. In year 1, Xandria went to only one grade-level colleague to talk about mathematics. She talked with this teacher frequently, usually during lunch. However, in year 2, Xandria's network expanded substantially. She reached out to more colleagues in her grade, reporting that they ''confer[red] regularly to talk about 'well how did it go?' You know, what kinds of things [are] happening in your room? And what do we need to do differently next time?'' She also sought out both coaches in her school, the principal, and a colleague in second grade. For example, she described the following exchange with the second-grade teacher:

> I just recently asked [second-grade teacher] about an [activity] that she uses with the children in second grade. . . . And so I asked her ''do you think that would be appropriate to use for first grade?'' Because you know it would help me a lot to think about what they know and what they don't know and what they can do and that sort of thing.

Xandria's network also extended beyond her school in year 2: She talked regularly with two teachers in other schools whom she met through her master's degree program.

But, by year 3, Xandria found that she had less time to interact with colleagues. She explained

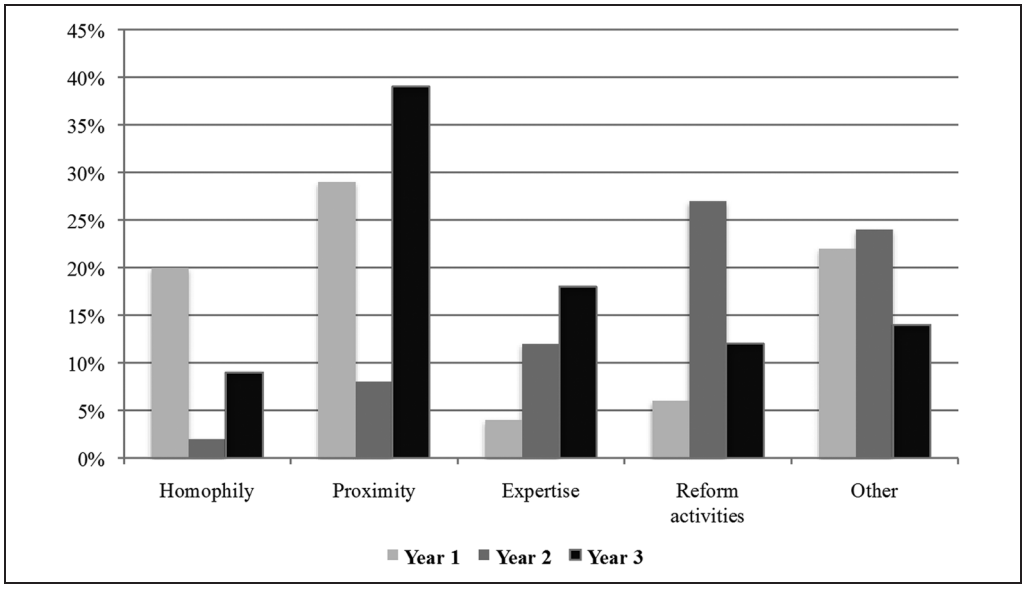

Figure 1. Reasons teachers sought out others in their networks. Percentages per year do not add up to 100 because reasons were double coded.

that the school no longer used biweekly meetings to discuss mathematics: ''We don't always discuss math. . . . We do talk a lot about how the math teachers can support literacy.'' And, indeed, her mathematics network contracted, such that she only talked with one coach, a subset of her grade-level colleagues, and one teacher in another grade.

Like Xandria, 10 of the 12 focal teachers had networks that started small, increased substantially in size and diversity in year 2, and contracted in year 3. The remaining two teachers had networks that steadily increased in size and, in one case, diversity. Winona, a second-grade and then kindergarten teacher in School G, had a network that started small but grew by a single teacher each year, in part facilitated by a change to a new grade level with more grade-level colleagues. Don, a fifth-grade teacher in the same school as Xandria, increased both the size and diversity of his network across the three years, in part because he became involved in district-wide activities that enabled him to connect with multiple teachers from other schools.

It is conceivable that it is simply a coincidence that most teachers' networks expanded and contracted at the same time as the district initiated, expanded, and then eliminated structures for teachers to meet. These two patterns might be concurrent but unrelated. To investigate this possibility, we analyzed the reasons teachers gave for reaching out to others to discuss mathematics. We found that the organizational changes associated with the mathematics initiative interrupted the modal ways that teachers formed ties in year 2 but became less important in year 3 as the initiative waned. This analysis, which we present below, supports our argument that shifts in the structure of teachers' networks were influenced by district policy.

As part of our social network protocol, we asked teachers why they went to some colleagues and not others to discuss mathematics. As you can see in Figure 1, proximity, homophily, expertise, and reform structures were the most prevalent reasons teachers formed ties.[6] Furthermore, teachers' reasons for forming ties shifted over the three years. (See Appendix A for definitions used in coding.)

In year 1, teachers' reasons for seeking out others echoed existing research on tie formation: Teachers were most likely to reach out to others because of proximity and homophily. In all four schools, teachers' classrooms were physically clustered by grade, fostering proximity with grade-level colleagues. For example, one teacher explained why she went to a grade-level

colleague: ''She is on my grade level. I see her at lunch. I see her during prep. And she is two or three rooms down from where my room is so it's a lot easier.'' Teachers were also most likely to identify those in their grade level as being ''like'' them in some respect, fostering homophily. For example, one teacher explained: ''Basically, both of our classes are on the same page. We're doing the same things. . . . She's my team. She's a colleague in my same grade level.'' The preference for proximity and homophily in year 1 resulted in social networks that largely comprised grade-level colleagues.

However, by year 2, proximity and homophily were no longer the main reasons that teachers sought out others to talk about mathematics. Instead, teachers were more likely to go to others for reasons related to reform activities. We coded ''reform activities'' when teachers referenced talking to others because of grade-level meetings, biweekly school professional development, district professional development, or coaching. These activities seemed to create a shared focus, bringing teachers together to work on improving aspects of their mathematics instruction. For example, one teacher explained why she went to another teacher after a grade-level meeting focused on fractions: ''We're just all really trying to have a better understanding of fractions or grids or multiplication and we'll just ask each other: 'How did you do that?''' Reasons related to reform activities accounted for 27 percent of 35 ties in year 2, an enormous increase. At the same time, there was a sharp decrease in the number of times that teachers went to others for reasons of homophily (down to 3 ties; 2 percent of total ties) and proximity (down to 10 ties; 8 percent of total ties).

There was also a shift in whom teachers turned to because of proximity in year 2. While teachers were most likely to mention proximity as a reason for seeking out grade-level colleagues in year 1, in year 2 they were most likely to go to teachers in other grades (6 ties), followed by those in their grade level (3 ties) and the coach (1 tie). This suggests that new reform structures not only influenced teachers' tie formation directly, by providing a common focus and opportunities for teachers to interact, but also influenced tie formation indirectly by creating proximity for teachers with new and different people.

Finally, in year 3, as the initiative was scaled back, reform activities as a reason for reaching out to colleagues declined substantially (see Figure 1). In the absence of a structure and focus for interaction, proximity increased as the most common reason for selecting others to discuss mathematics, driving teachers to grade-level colleagues. Of the 36 ties formed due to proximity in year 3, 32 were with grade-level colleagues and 3 were with coaches.

This analysis suggests that the new reform activities interrupted the modal ways that teachers established ties, at least for a short time. The increase in occasions for teachers to meet about mathematics created more opportunities for teachers to interact in regular and sustained ways around a shared focus, which seemed to foster tie development that often spanned beyond grade level to other areas of the school. The move toward more cross-grade ties is particularly intriguing since prior research suggests that ties that bridge functional areas—as happens when teachers reach out to those in other grade levels—are much less likely to be formed than those within functional areas (Rivera et al. 2010). Indeed, when structural supports for this kind of interaction were removed in year 3, the tie formation process shifted again. In the absence of structured opportunities to meet, teachers no longer formed new ties because of reform activities and were unable to maintain ties formed during the prior year. Given limited time during the day when they were not directly responsible for children, teachers seemed to make do with those nearby if they had a question or needed support related to mathematics. To the degree that it created and took away opportunities for people to interact in regular, sustained ways, district policy appeared to influence both tie formation and dissolution.[7]

Enabling strategic choice: school meetings and knowledge of expertise. We also identified a more subtle way that the mathematics initiative appeared to influence network formation. Structures put in place for the initiative provided opportunities for teachers to learn where expertise was located in their school, enabling them to make increasingly strategic decisions about who to ask for advice.

The benefit that networks confer likely depends upon the expertise that is available among the people who make up that network (Adler and Kwon 2002). Individuals may be more or less skilled at developing networks that provide access to expertise. Indeed, one of the consequences of norms of privacy and autonomy in schools is that teachers do not always know what others are

doing in their classrooms and whether they are doing it well (Little 1990), making it difficult to make judgments about the quality of advice they are likely to receive. In our study, as meetings became more focused on mathematics teaching and learning in year 2, they created opportunities for people to learn the location of expertise. As a result, teachers not only increasingly sought out others for expertise but became better at making those judgments. To make this argument, we provide evidence that teachers increasingly selected others for reasons of expertise across all three years. We then show that these assessments of expertise became increasingly accurate. Finally, we discuss the consequences of this pattern for the configuration of teachers' social networks.

Returning to Figure 1, teachers sought out others for reasons of expertise with increasing frequency across the three years. In year 1, teachers rarely sought out others because they saw them as expert. But, starting in year 2, this steadily increased. For example, in year 2, one teacher explained why she went to a colleague:

> She's just very knowledgeable, very good with the kids. . . . I've seen her in action and she is really good at strategizing, really good at having kids think the processes out before they just do them or speak them.

Even as teachers' ties contracted in year 3, their inclination to seek out expert others continued to increase.

At the same time, whom teachers sought out for their expertise also changed. In year 1, all ties formed because of perception of expertise were to coaches. In year 2, all but one of the ties formed because of a perception of expertise were to grade-level colleagues or coaches. But, in year 3, teachers identified colleagues in other grade levels for this reason. In fact, expertise was the main reason that focal teachers sought out colleagues in other grades that year.

Kathy, a second-grade teacher in School E, illustrates this pattern well. In year 1, Kathy's network comprised grade-level colleagues and two school-based coaches. However, she did not report going to any of these individuals because she saw them as having expertise. Instead, she sought them out for reasons of homophily or reform activities. In year 2, Kathy's network remained confined to her grade level and coaches, although she also sought out assistance from a coach at another school whom she met in a district-sponsored activity. She continued to go to grade-level colleagues for reasons of homophily and reform structure in year 2 but sought out the three coaches because she saw them as having expertise. Finally, by year 3, Kathy's network was smaller, but she selected more members of her network for their expertise, including four grade-level teachers and the remaining coach in her school.

Like Kathy, 8 of 12 teachers in our sample increasingly went to others for reasons of expertise across the three years. Three of the four teachers who did not were in School G, a school with a high degree of dissension about mathematics. It is possible that the lack of respect that some teachers had for their colleagues led to a lower inclination in School G to seek out others for reasons of expertise.[8]

It appears that opportunities to interact with others about mathematics enabled teachers in most schools to learn where expertise in mathematics was located. Teachers not only developed an appetite for expertise, driving their reasons for seeking out others, but also improved in their ability to identify those in the school with expertise. When teachers told us that they went to others because they were knowledgeable, it reflected their perceptions of the expertise of others. We also independently analyzed teachers' and coaches' expertise (see Appendix A for criteria for determining expertise). Across the three years, focal teachers' perceptions of expertise moved progressively closer to our assessment.

There are two ways to show this pattern. First, we assessed whether individuals whom focal teachers perceived as expert actually had expertise according to our metric. As Table 2 shows, there was an increase from year 2 to year 3 in the percentage of those teachers nominated for expertise who actually had it.[9] Second, we assessed the match between the people focal teachers selected as having expertise and those in their network who had expertise according to our metric. That is, of all the people in their network with expertise, what percentage did focal teachers perceive as having expertise? Table 2 shows that there was a substantial increase in this percentage across the three years as well. For example, in year 1, teachers identified two people as having expertise, but there were also 19 others in focal teachers' networks who we considered to have moderate or high expertise. Thus, focal teachers only

Table 2. Expertise as Rated by Teachers and Researchers.

	Year 1	Year 2	Year 3
Number of ties teacher nominated because of expertise	2	15	17
Number of teacher-nominated ties rated as moderate or high expertise on researcher metric	2	9	12
Degree to which teacher-nominated ties were expert on researcher metric	100% (2/2)	60% (9/15)	71% (12/17)
Total number of ties in teachers' network rated as moderate or high expertise on researcher metric	21	40	28
Teacher accuracy in locating expertise in network	9% (2/21)	23% (9/40)	43% (12/28)

accurately identified 9 percent of those with expertise in their network. In contrast, in year 3, focal teachers identified 43 percent of the individuals in their networks with expertise accurately. Teachers in three of the four schools improved in their ability to identify expertise in their networks over time. The three teachers in School G did not improve this competency.

Because most teachers became increasingly accurate in identifying expertise, they were able to maintain expertise in their network, even as the networks decreased in size and diversity. In year 2, for example, we judged that 32 percent of teachers' ties had moderate or high expertise. By year 3, this held steady. At the same time, teachers dramatically increased the expertise in ties that stretched beyond the grade level. In year 2, just over 40 percent of focal teachers' ties outside of their grade level had moderate or high expertise. That rose to just over 85 percent in year 3. Thus, even though teachers were reaching out to fewer people outside their grade in year 3, those they did seek out were more likely to have moderate or high expertise. Faced with less time and fewer structures to meet, teachers in three out of four schools seemed to draw on a more robust understanding of what others in the school actually knew about mathematics to make more strategic choices about where to seek advice about mathematics instruction.[10]

Taken together, this suggests that social policy can influence social networks by creating structures and focus that influence the formation of ties. District policy created new structures that brought teachers together around a shared focus on improving mathematics instruction. This appeared to influence who teachers interacted with and their reasons for reaching out to others. To the degree that interaction in these structures provided a window into others' knowledge and practices, district policy also seemed to create opportunities to develop insight into the social location of expertise, fostering tie formation processes that were more targeted and strategic.

Resource Availability. One of the central ways that social networks bring value is by facilitating access to resources that are available at the network nodes (Adler and Kwon 2002; Lin 2001). We argue that district policy influenced the resources that teachers accessed through their network transactions in three ways: (1) by providing information that subsequently flowed to teachers through the networks, (2) by providing materials that teachers acquired via their colleagues, and (3) by providing professional development that increased the level and breadth of available expertise.

In this section, we discuss the way that district policy appeared to influence teachers' access to each of these resources in their social networks. We highlight the role of the coach and outside contacts as boundary spanners who brought district resources to teachers via their networks. Further, we show that materials and expertise were more durable than information, having a sustained presence in the network even as the district initiative wound down.

Information. The district influenced the resources available to teachers in their networks by supplying information that teachers subsequently accessed in social network exchanges. To draw this conclusion, we analyzed 361 social network interactions across the three years for which we had sufficient information to code for resource flows. A large percentage of interactions involved sharing information, a subset of which originated from the district (see Figure 2). Teachers shared

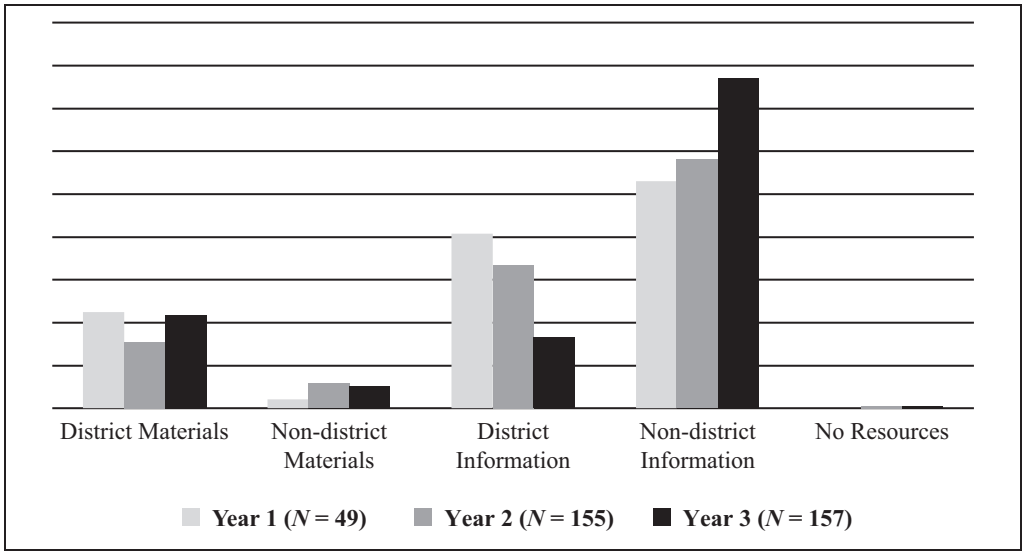

Figure 2. Resources flowing to teachers. Percentages per year do not add up to 100 because interactions were double coded.

information about mathematics that they learned at district-sponsored professional development. The coach also frequently provided information to teachers about district expectations for using the curriculum, reviewing test results, or administering interim assessments. For example, one teacher explained an interaction with a colleague: ''She wasn't familiar with the [district mathematics assessment] so I told her . . . what to expect. And she said that was helpful to know those things before she got it.''

Overall, teachers' access to information from the district through their networks declined across the three years, while information flowing from other sources greatly increased. Thus, by year 3, teachers were still accessing information in their networks, but the information that emanated from the district declined sharply.

Across all three years, teachers were most likely to access district information when interacting with coaches (see Table 3). Those outside the school also played an important role, accounting for 35 percent of interactions involving district information. But this role declined precipitously over time. As it did, teachers relied more heavily on one another to learn about district information. Finally, teachers rarely gained access to district information while interacting with school administrators.

Materials. The second way that district policy contributed to the resources that flowed in teachers' social networks was by providing materials related to mathematics, which subsequently found their way into teachers' network transactions. As part of the mathematics initiative, the district purchased curricular materials, including textbooks, manipulatives, and software. It also distributed a range of tools at professional developments that helped teachers link the curriculum to state standards and tests, conduct informal assessments, and plan activities. Teachers received some of these materials directly from the district, especially textbooks. But our observations of social network transactions provide evidence that teachers also gained access to district materials indirectly via their social networks. For example, one teacher in School F explained the materials she had received via her coach: ''She is always really supportive and anything that we might need to help us teach *Investigations*, she's always really good about trying to get the materials that we need.''

Teachers gained access to district materials through interaction with colleagues in their networks in all three years. However, in contrast with district information, which declined over time, the presence of district materials in teachers' social network exchanged started high in year 1, dipped slightly in year 2, and then increased again in year 3 (see Figure 2). This suggests that materials are perhaps a more durable resource than information, as they remained salient in networks transactions even as the district withdrew support for the initiative.

Table 3. Percent of Interactions with Transfer of District Information and Materials, by Functional Area.

	Year 1	Year 2	Year 3
District information			
Teachers in grade level	10	39	42
Teachers in other grade levels	5	2	8
Coaches (one-on-one and in groups)	50	52	50
Administrators	0	3	0
Those outside the school	35	4	0
Total	100	100	100
District materials			
Teachers in grade level	55	25	79
Teachers in other grade levels	0	4	9
Coaches (one-on-one and in groups)	27	50	12
Administrators	0	17	0
Those outside the school	18	4	0
Total	100	100	100

Coaches played an important role here, although less so than with district information. Their role was also sensitive to the structures and focus afforded by the mathematics initiative. As the district initiative expanded and contracted, so too did the coach's role in bringing district materials into teachers' networks (see Table 3). As with information, teachers' ties outside the school conveyed district materials in year 1 but subsequently declined precipitously. While teachers were likely to be a source of district materials for one another for all three years, teacher-to-teacher interaction became even more important with the decline of the role of the coach and outside contacts. This suggests that materials continued to circulate within teachers' social networks well after the district stopped supplying them to schools.

Expertise. The district also provided resources to networks by building the capacity of individuals throughout the district. When teachers went to others, they interacted with individuals with expertise developed by district actions. As discussed earlier, over the course of the study, teachers developed an appetite for expertise and increasingly sought out others with it. But teachers' desire for expertise would not be of much use if there were few people in their environment with that expertise. It is here that the district policy played a role. Most of the people in teachers' networks with expertise had it because they had participated in district-sponsored professional development. In year 1, 67 percent of people with moderate or high expertise in teachers' networks (14 of 21) gained that expertise by participating in district-sponsored professional development. In year 2, this grew to 75 percent (31 of 41). In year 3, 90 percent of individuals in teachers' social networks with moderate or high expertise (26 of 29) developed it this way. By investing in professional development, the district increased the number of people in schools who were knowledgeable about mathematics instruction. As teachers became increasingly interested in having those with expertise in their network, there were more people in the school to choose from who had those qualities.

Coaches were an especially important source of district-developed expertise. In year 1, for example, 71 percent of people in teachers' networks with moderate or high expertise (15 of 21) were coaches, and all had expertise from participating in current or prior district programs. However, as with information and resources, this pattern shifted over time such that by year 3, less than half of the individuals with moderate or high expertise in teachers' networks were coaches. Furthermore, like district materials but in contrast with district information, expertise as a resource proved durable. While the district initiative waned in year 3, teachers' access to expertise in their networks remained and in some cases increased.

Taken together, this suggests that district policy played an important role in providing resources—information, materials, and expertise—that became part of teachers' network transactions. However, some resources had more staying power than others. As the district initiative expanded and contracted, district materials remained and expertise increased as a presence

in teachers' network exchanges. In contrast, district information was more sensitive to district focus and attention, declining over time as a salient feature of social network interactions. By year 3, even though the district mathematics initiative was largely over, teachers were still accessing materials related to the district mathematics agenda and accessing mathematics expertise via their network. But they made meaning of mathematical ideas by drawing on information from a range of nondistrict sources. Finally, coaches and, to a lesser extent, those outside the school played a role in carrying district resources into teachers' networks. The district invested in coaches' training, which increased the expertise that teachers had access to in everyday interactions. Coaches and outside contacts also functioned as boundary spanners, brokering information and materials from the district into teachers' social networks, although this role was sensitive to the rise and fall of the initiative as a whole.

Nature of Interaction. Finally, district policy influenced social relations by shaping the nature of interaction within teachers' networks. Few studies of social networks investigate the nature of interaction, much less the role of organizational and policy context in fostering particular kinds of interaction. However, by combining observational data on interaction with social network analysis, we were able to look inside the black box and characterize the nature of network transactions. We found that interaction in social networks was not all the same. It varied greatly in depth, from quick exchanges about how the students were doing or about a pending deadline to in-depth and substantive conversations about mathematical content or the nature of student learning. These varied interactions have different potential to foster the outcomes identified by social network theorists, making it more or less likely that individuals share valuable information, engage in joint problem solving, or learn in interaction with others. In this section, we argue that the district influenced the nature of interaction in networks by designing specific and highly patterned ways of talking about mathematics—what we call ''routines of interaction''—which then diffused to the school via the coach. These routines of interaction interrupted the typical ways that teachers talk about instruction, introducing new patterns that persisted even as the initiative waned.

To make this argument, we begin by identifying district-designed routines of interaction that were used with coaches during professional development and which coaches, in turn, were asked to use with teachers in schools. Routines are ''repetitive, recognizable patterns of interdependent actions, carried out by multiple actors'' (Feldman and Pentland 2003:95). Routines of interaction are routines intended to guide conversation between adults on matters of instruction. We then show that district-designed routines of interaction became prominent features of focal teachers' networks and that, over time, these routines diffused from coach-teacher interaction to teacher-teacher interaction. Finally, we show that district-designed routines influenced the depth of conversation about mathematics in teachers' social networks.

District-designed routines. As part of the mathematics initiative, district leadership designed training activities for coaches that included specific approaches to talking about mathematics with others. Some of these approaches constituted routines of interaction. By analyzing interviews with district mathematics leaders and observations of professional development for coaches, we identified eight distinct routines of interaction that district mathematics leaders repeatedly used with coaches. Coaches were then asked to use these approaches with teachers. These routines included such things as task analysis, investigations of students' problem-solving strategies, structured reflection on practice, and routines for looking at student data, among others (see Appendix A for a description of routines). In each routine, facilitators led coaches through a predictable set of interactions, asking a specific set of questions to guide discussion.

For example, coaches were frequently asked to analyze strategies that children were using to solve mathematics problems and then brainstorm ways to build on and extend children's strategies. In this routine, the facilitator would ask coaches to view a video of a classroom or analyze a piece of student work to identify the strategies children were using to solve the problems. For example, the following excerpt from field notes illustrates this routine as observed in a professional development session for coaches in year 2:

> When I came to the Art Room where the professional development meeting was held, the math coaches were watching a video clip prepared by Laverne [professional development provider]. In that video, Laverne was interviewing with a second

> grader. She asked questions about two-digit addition and subtraction (e.g., 28 + 24, 34 – 16). The student was answering the questions using interlocking cubes. After the video, Laverne asked the coaches to talk in their group about the student's strategies displayed in the video. Participants discussed in their groups about the student's strategies for two-digit addition and subtraction. . . . Then the facilitator asked the participants about the student's way of solving the subtraction problem for 34 – 16.

Through professional development sessions like this one, coaches learned and practiced this and other district-designed routines.

District routines and teacher interaction. The district-designed routines introduced to coaches subsequently turned up in teachers' interactions with each other. We analyzed 409 interactions in teachers' networks that had adequate information to code the content of interaction. District-designed routines of interaction accounted for a subset of interaction in each year (see Table 4). For example, 12 percent of interactions in year 2 and just over 5 percent in year 3 involved the student strategies routine. For example, Larissa, a teacher in School F, described an interaction she had with other teachers: ''We bring some story problems that the kids are working on and really look at how their strategies are working and what strategies we need to maybe focus on or where we need to move the student from where they are now.'' In contrast to research that describes teacher interaction as largely consisting of quick exchanges of stories, limited assistance that rarely delves into substantive issues, and sharing of materials or activities (Little 1990; Lortie 1975), when teachers engaged in district-designed routines, their interaction was extended, structured, and focused on mathematics teaching and student learning. Thus, district-designed routines fostered interaction that was distinctly counter-normative.

The presence of district-designed routines of interaction increased from year 1 to 2 as the district intensified its focus on mathematics (see Table 4). But it declined in year 3 as the district ended the mathematics initiative. Interaction with coaches was hardest hit. This decrease is likely because even though teachers continued to nominate coaches as part of their social networks in year 3, they had greatly reduced contact with them because of cutbacks in one-on-one coaching and coach-led professional development. In the absence of sustained interaction with coaches, opportunities to engage in district-designed routines with them decreased. In year 3, teacher-coach interaction was more likely to involve quick exchanges of advice or sharing than district-designed routines.

Table 4. Percentage of Total Interactions Involving District-Designed Routines.

District-designed routines	Year 1	Year 2	Year 3
Reflection	6	3	1
Task analysis	0	4	1
Student strategies	4	12	5
Goal setting	2	0	0
Monitoring notes	2	0	0
Mapping	4	10	3
Demonstration	4	3	2
Examining data	4	6	11
Total	26	38	23

Note: *n* for year 1 = 52 interactions; *n* for year 2 = 200 interactions; *n* for year 3 = 157 interactions.

This rise-and-fall pattern for district-designed routines held for 10 of 12 teachers. The remaining two teachers—Florence and Winona, both kindergarten teachers in school G—experienced a steady decline of district-designed routines.[11] While Florence was supportive of the mathematics initiative, Winona and others in the grade level were not. Both teachers spent less and less time talking with their colleagues in depth about the curriculum. Thus, despite the fact that they had good-sized social networks related to mathematics (Florence had six others in her network and Winona had seven), they spent little time engaging in the district-designed routines of interaction in the later years of the study.

At the same time as district-designed routines increased and decreased as a salient part of most teachers' interactions, they also moved to different parts of teachers' networks. As Table 5 shows, district-designed routines were largely confined to coach-teacher interaction in year 1 as coaches brought routines from district professional development to their interactions with teachers. In year 2, the district-designed routines continued to be a feature of coach-teacher interaction but also showed up more frequently in teacher-teacher

Table 5. Percentage of Teachers' Interactions with District-designed Routines, by Functional Area.

	Year 1	Year 2	Year 3
Teachers in grade level	13	31	63
Teachers in other grade levels	0	12	22
Coaches (one-on-one and in groups)	73	53	13
Administrators	7	0	0
Those outside the school	7	4	2
Total	100	100	100

Note: *n* for year 1 = 13 interactions; *n* for year 2 = 74 interactions; *n* for year 3 = 30 interactions.

interaction. Finally, in year 3, the majority of district-designed routines were found in teacher interaction with others at their grade level and throughout the school.

It appears that participation in district-designed routines during the early years of the initiative fostered new norms of interaction for teachers. Rather than being counter-normative to talk about student learning or instructional strategies in detail, the district-designed routines legitimized these issues and provided models for talking about them in more depth. By year 3, many teachers were regularly initiating these routines on their own. For example, Sophia and her colleagues in School E embraced several district-designed routines as the way they did business in their grade-level group by year 3. Sophia described how teachers, on their own, initiated lesson demonstrations for each other that they had previously experienced only with the coaches:

> I started math logs this year to have them write in their math logs, for example, like: Which holds more? . . . I want them to really show me their meaning of it in their math logs, so then I can assess and kinda see do they understand the concept. . . . And so [my grade-level colleague] says ''I'm doing math logs'' and so she modeled it for me. My kids came right into her classroom and we even did the debrief afterwards.

This suggests that the district-designed routines that entered teachers' social networks via the coach subsequently diffused into teacher-teacher interaction, where they remained in most teachers' networks, even after the policy support for such interaction was withdrawn.[12]

Consequences of district-designed routines of interaction. The presence of district-designed routines was consequential because they tended to foster in-depth conversations. We analyzed the depth of interactions each year. Nearly all district-designed routines yielded moderate or high depth interaction at a higher rate than exchanges that did not involve routines (see Table 6). Interactions involving district-designed routines tended to involve specific conversations about what or how students were learning, the nature of the mathematics involved in lessons, or the pedagogical principles underlying instructional strategies. By contrast, those that did not involve district-designed routines tended to involve general descriptions of lessons, a focus on technical matters involved in orchestrating a lesson, or fleeting conversations about pacing or scheduling. That is, they were at a low level of depth.

Thus, this study provides evidence that it is possible for district policy makers to influence interaction in teachers' informal networks. The district developed new forms of interaction that coaches brought into teachers' social networks, where they interrupted forms of interaction that predominate in most schools. While teachers first engaged with these routines with the coach, they subsequently used them in interaction with their colleagues without the coach present. In this way, the district-designed routines appeared to diffuse from the district to schools via the coaches and into teachers' one-on-one interactions with one another.

DISCUSSION

It has become increasingly clear that teachers' social networks can play an important role in

Table 6. Depth of Interaction[a]: District-designed Routines Compared with Other Interactions.

	Year 1		Year 2		Year 3		Total	
Routine	Low	Mod/High	Low	Mod/High	Low	Mod/High	Low	Mod/High
District-designed routines								
Reflection	33%	67%	50%	50%	0%	100%	33%	67%
Task analysis	—	—	0	100%	50%	50%	18%	82%
Student strategies	0	100%	4%	96%	13%	87%	6%	94%
Goal setting	0	100%	—	—	—	—	0	100%
Monitoring notes	0	100%	—	—	—	—	0	100%
Mapping	100%	0	50%	50%	80%	20%	69%	31%
Demonstration	0	100%	0	100%	25%	75%	9%	91%
Examining data	100%	0	8%	92%	65%	35%	58%	42%
Other interactions	82%	18%	72%	28%	85%	15%	78%	22%

Note: *n* of year 1 = 52 interactions; *n* of year 2 = 200 interactions; *n* of year 3 = 157 interactions.
a. Depth of interaction was classified as low or moderate/high.

teacher learning and organizational change (Coburn et al. 2012; Frank et al. 2004; Moolenaar and Sleegers 2010; Penuel et al. 2010). It is less clear what influences teachers' social networks. Why do some teachers have networks that are more likely to support individual and organizational change, while others do not? This study is a first step in answering this question. It shows that teachers' social networks are embedded in and affected by their policy context. More specifically, we show that policy can influence the tie formation process by creating new structures for regular and sustained interaction. When they are focused on substantive issues, these structures can also provide opportunities for teachers to learn the social location of expertise, which can alter teachers' strategies for reaching out to others and the social networks that result. We also show that policy can influence the degree to which networks provided access to valuable resources. District information and materials not only entered the school through formal channels; they reached teachers through their informal networks as well. The district also contributed resources to teachers' networks by building the capacity of coaches and others through professional development such that when teachers needed advice about mathematics, they found more people in their environment with expertise.

Perhaps most unexpectedly, we show that social policy can influence how teachers actually interact with others in networks. The district in our study designed new routines of interaction, which coaches, in turn, brought into schools. These routines diffused through informal networks, supplanting the conventional ways that teachers interact with one another. These counter-normative routines then persisted, becoming part of some teachers' repertoires of interaction with their colleagues.

However, social policy can also disrupt ties, interrupt the flow of resources, and remove supports for new routines. New ties, especially those that stretch across functional areas, are fragile (Burt 2000). Absent continued support for regular and sustained interaction and a shared focus that initiatives can provide, ties can decay over time. Furthermore, while coaches can play an important role in brokering resources and routines, their role may be sensitive to changes in district policy, receding as support for their work with teachers declines.

These findings have implications for research on social networks and public schools. First, this study extends research on the organizational embeddedness of social networks by attending to the role of social policy. Social network researchers have historically paid little attention to the role of formal bureaucratic mechanisms such as organizational structure or policy in influencing social relations (Adler and Kwon 2002). Instead, they tend to emphasize the emergent character of social networks, focusing on the choices individuals make as they seek out others with whom to interact, neglecting the social arrangements and organizational conditions that shape individual choice. Those scholars who do attend to context focus exclusively on features of the organization.

We show that social networks are embedded in policy contexts as well. Policy initiatives create new structures, roles, and focus that influence tie formation, maintenance, and decay. They provide and withdraw significant resources, which may influence the resources that individuals access via their networks. And policy initiatives can interrupt or reinforce modal forms of interaction, shaping how teachers talk with others in network transactions, what they talk about, and, consequently, what they have opportunity to learn from one another. Scholars of embeddedness provide convincing evidence that social network processes condition individual action. We show that social policy can condition these social network processes.

It may be particularly important to understand the embeddedness of teachers' social networks. Teachers spend most of their workday as the only adult in their classrooms. Longstanding norms of privacy have worked against teachers reaching out to others for substantive conversation. By uncovering the way that teachers' social networks are embedded in the organization and policy context, we can begin to understand an important mechanism by which these occupational norms are interrupted or sustained. This insight can help explain variation in the degree to which teachers have networks that are conducive to instructional improvement. It also provides insight into leverage points for encouraging network development and sustainability in schools.

Second, this study extends our understanding of tie formation. Prior research identifies multiple factors that predict tie formation and maintenance but does not investigate how these factors interact with one another (Rivera et al. 2010) or shift over time (Powell et al. 2005 is an exception). We show that the reasons teachers seek out others—what Powell and colleagues (2005) call ''logics of attachment''—can interact and shift over time. At the beginning of the study, teachers sought out others because of proximity and homophily, perhaps because they trusted those they saw as having common issues, concerns, and shared language or those they saw frequently. This increased trust may have mitigated the risk of talking to colleagues about new instructional reform. But, over time, reform activities created new forums for interaction, making proximity less crucial. And a new focus provided by the reform and reinforced by substantive interaction in meetings and professional development raised the profile of expertise, while diminishing the importance of homophily. Thus, teachers shifted from traditional reasons for forming ties—homophily and proximity—toward more instructionally targeted and mathematically focused ones. As a result, teachers' social networks become more diverse, with higher levels of expertise. This suggests that factors influencing tie formation are not static. Rather, actors' motivation for reaching out to others may vary depending upon organizational and environmental conditions.

This study also contributes to research on tie formation by identifying an additional mechanism involved: knowledge of the location of expertise. Perceptions of others are formed through direct interaction, observation, and third-party commentary (Cross and Borgatti 2000). Because of occupational norms of privacy and autonomy, many teachers have only indirect and imperfect information about other teachers' daily activities and areas of expertise (Little 1990). In this study, the district unwittingly created a mechanism for teachers to learn what their colleagues actually knew about mathematics. Teachers used this knowledge to be more strategic about whom they asked for advice, even as they were less likely to seek out others overall. Given that knowledge of available expertise in the local environment is positively associated with enhanced individual and organizational performance (Faraj and Sproull 2000; Liang, Moreland, and Argote 1995; Moreland and Myaskovsky 2000), this unanticipated outcome of district policy may have consequences for whether social networks foster organizational learning and change—something to be investigated in future studies.

Third, this study provides insight into the role of policy in providing the resources that can be accessed via social networks. Theorists argue that social network benefits like teacher learning lie, in part, in the resources gained via interaction with others. But networks vary greatly in the level and kind of resources they provide (Lin 2001; Small 2006, 2009). Theoretical work suggests that organizations can play a role in the resources available in networks (Small 2009). This study provides empirical evidence to support this claim. We show that the district initiative provided information, materials, and expertise to schools, which teachers subsequently accessed in network exchanges. In so doing, we illustrate how resources available to individuals via their social networks are not just mobilized by members of the networks themselves, as suggested by social

network scholars (Lin 2001); they may also be mobilized by social policy (see, also, Small 2009 on this point).

We also highlight a key mechanism by which resources permeate school boundaries and enter teachers' networks. Existing research suggests that school administrators are the primary route through which resources and information enter schools (Rallis and Goldring 2000; Smith and Wohlstetter 2001). Yet, in this study, teachers' interactions with administrators rarely involved district materials, information, routines, or expertise. Instead, mathematics coaches and, to a lesser extent, teachers' contacts outside of schools were more likely to play this boundary-spanning role. Thus, this study suggests that rather than influencing access to resources and expertise and the nature of social interaction directly via the hierarchical authority structure, policy may influence these social and organizational processes indirectly via teachers' informal networks.

Finally, this study provides insight into the content of social network transactions. Most social network research tends to be structuralist, explaining various network processes and outcomes in terms of network structure. Rather than studying network transactions directly, these studies infer these processes from information about tie strength or network structures (Borgatti and Ofem 2010). Thus, we have little information about what actually happens in network transactions—what resources flow or what knowledge is shared and how. This study investigates these processes directly rather than inferring them. We provide evidence that not all social network transactions are the same, even in networks with similar size and configuration. We paint a portrait of the flow of multiple kinds of resources—information, materials, and expertise—from the district and other sources. We demonstrate that interaction around resources can vary greatly in depth, from swapping materials and activities to having substantive conversations about mathematical content, and from in-depth problem solving to quick exchanges of information. This suggests that making inferences about social network transactions from the structure of networks alone may be limited; it misses variability in crucial processes that are likely related to the social network outcomes we seek to explain. Thus, this study opens up new avenues for research, pointing to the need to investigate resource flows and forms of interaction directly to understand how they relate to key network outcomes.

Ultimately, this study provides evidence that teachers' social networks are more amenable to outside influence than previously thought. Social policy can play a role in fostering conditions in schools within which teachers seek out their colleagues, share information, solve problems, and learn from one another in their networks. This suggests that understanding the role of teachers' social relations in individual change, organizational processes, and student outcomes may require greater attention to the ways that social networks are, themselves, embedded in and affected by their organizational and policy context.

Appendix A. Definitions Used in Coding.

Code	Definition
Researcher assessment of expertise	
High	High expertise is defined as (1) four or more intensive professional development experiences or (2) a math major in undergraduate or specialization in mathematics education in graduate work accompanied by two or more intensive professional development experiences.
Moderate	Moderate expertise is defined as (1) two or three intensive professional development experiences or (2) mathematics major as an undergraduate or specialization in mathematics in graduate school accompanied by at least some opportunity to learn about pedagogical approaches consistent with the *Investigations* curriculum.
Low	Low expertise is defined as (1) one or fewer intensive professional development experiences and (2) no formal mathematics training in undergraduate or graduate school, or a mathematics major or specialization in mathematics absent at least some opportunity to learn about pedagogical approaches consistent with the *Investigations* curriculum.
Reasons for forming ties	
Homophily	Teachers form ties with others because they perceive them to be explicitly like themselves in some manner. Examples of homophily include grade level, type of school, or gender. Teachers must identify a person as "like" themselves on a given dimension to be considered homophily.
Proximity	Teachers form ties with others because they are physically near for example, work on the same floor or hall, see each other on the playground, or see each other in the hall, in the workroom, or at lunch.
Reform activities	Teachers form ties with others to work on aspects of the reform: for example, coaching, program development, or joint assessment.
Perception of expertise	Teachers form ties with others because they perceive them to have expertise: for example, many years of teaching experience, or training and knowledge of mathematics.
Other	Teachers form ties for other reasons: for example, because they perceive similar values about appropriate instruction, because they are friends or "get along," or because they have a shared professional history.
Depth	
Low	Talk related to one or more of the following: how to use materials; how to coordinate between the text, standards, assessments, and pacing guides; how to organize the classroom; sharing materials or activities; general discussions of how a lesson went or whether or not students were "getting it."
Medium	Talk related to one or more of the following: specific discussion of how lessons went that includes a discussion of why; planning for specific lessons that is detailed and includes a discussion of why; specific and detailed discussion of whether students were learning (but not how students learn); discussion of instructional strategies in the context of observations; doing mathematics problems together with discussion.
High	Talk related to one or more of the following: pedagogical principles underlying instructional approaches; how students learn or the nature of students' mathematical thinking; mathematical principles or concepts.

(continued)

Appendix A. (continued)

Code	Definition
District-designed routines of interaction	
Reflection	Discussion involves individual self-assessment. Can be done in relation to a lesson that has been observed or when looking at lesson plans accompanied by artifacts of student work. Involves one or more of the following: reiterating instructional goals, analysis of student learning, reflection on what went well and what could be improved.
Task analysis	Participants analyze a mathematical task—in textbook, handout, or while watching a lesson live or on video. "Where's the mathematics?" "What's the objective?" Analyze mathematical content in the task, followed by discussion of instructional strategies for addressing that content.
Student strategies	Discussion involves looking at student work, interviewing a student, or observing a lesson (live or on video) and then analyzing the strategies students are using for problem solving. Often, discussion extends to instructional approaches to use in light of these student strategies, but not always.
Goal setting	Individuals set goals for aspects of their instruction that they are going to work on, specifying indicators that will alert them if their instruction has improved in response.
Monitoring notes	Discussion of monitoring notes kept by teachers or others on student understanding. Discussion involves specifying goal, reviewing notes for individual students, analyzing nature of student learning toward the goal, discussing next steps for students in light of analysis.
Mapping	Activities where teachers or others map the relationship between the state standards, the mathematics curriculum, and interim assessments.
Demonstration	One individual demonstrates a lesson or instructional technique in a teacher's classroom, followed by a structured debrief by one or more others.
Examining data	One of three protocols for looking at evidence of student learning: (1) Analyzing student work using rubrics; classifying students as far below expectations, approaching expectations, meets expectations, or exceeds expectations; looking for patterns across students. (2) Analyzing student test score data, identifying standards where students are weak, setting instructional goals, and brainstorming instructional strategies for meeting these goals. (3) Analyzing student test scores, identifying individual students at the edge of a given category, identifying instructional strategies to help individual student move to the next level.
Resources	
Information	Teachers exchange information related to the mathematics initiative or mathematics instruction, including how to use material resources, student learning, student achievement, instructional approaches, and/or services.
Materials	Teachers exchange material resources such as math manipulatives, worksheets, activities, assessments, and the curriculum itself.
Services	Teachers gain access to or learn about the availability of professional development sessions provided by the district or other organization.

Table B: Characteristics of case study schools.

School	Number Students	Race/ Ethnicity of Students	Free/ Reduced Lunch	English Language Learners	Overall Human Capital	Overall Social Capital
School E	883	9% African-American 80% Hispanic 9% White	85%	45%	Low	High
School F	914	7% African-American 85% Hispanic 1% Native American 1% Other	93%	57%	High	High
School G	644	5% African-American 89% Hispanic 5% White 1% Native American	99%	52%	Low	Low
School H	1114	9% African-American 70% Hispanic 19% White 1% Asian 1% Native American	73%	45%	High	Low

Methodological Appendix

To investigate the relationship between social policy and teachers' social networks, we draw on data from a longitudinal study that focused on how district reform strategies interacted with human and social capital in the implementation of ambitious mathematics curricula in two school districts. For this article, we draw on data from one district for which we have complete social network data over the three years of the study. Here, we provide further detail on some of our methodological choices to supplement the discussion in the full article.

Further details on the sample

Because the larger study was interested in how schools with different levels of social and human capital implemented the new mathematics curriculum, we purposively sampled (Strauss and Corbin 1990) four elementary schools that varied along these two dimensions. Selection was based on recommendations from the district director of mathematics. Specifically, we asked the director to nominate schools where the faculty had, on average, relatively high and low levels of human and social capital, with human capital described as mathematics instructional expertise and social capital described as interaction about mathematics instruction. To guide selection, we developed an extensive rubric that outlined specific indicators of high and low social capital and high and low human capital, which we shared with the district mathematics leadership. (The complete rubric is available upon request from the first author.) The district mathematics leader was well-positioned to place schools on the rubric because she had extensive knowledge of school organizational conditions and mathematics instruction in the district elementary schools. She spent one day per month in each elementary school in the district, observing classrooms and working with the school leadership. She also spent one day per week providing professional development to the mathematics coaches, during which time coaches discussed the conditions in their schools.

Next, we conducted preliminary site visits for each nominated school, interviewing the principal, coaches, and key teachers about the nature of the social interaction in the school and level of expertise in mathematics. We analyzed the preliminary interview data using our rubric, which confirmed that the four schools nominated by the mathematics director varied with respect to overall levels of interaction around mathematics and the level of instructional expertise. The final sample thus included four contrasting organizational conditions: one school with strong professional community and strong teacher expertise, one with strong professional community and weak teacher expertise, one with weak professional community and strong teacher expertise, and one with weak professional community and weak teacher expertise. See Appendix Table B for information about the four schools.

We selected four focal teachers in three schools. In the fourth—school H—we were only able to select two focal teachers for logistical reasons.[13] Teachers at all four schools were selected to represent a range of grades and attitudes toward the new curriculum.[14] Although we relied on principal recommendation to identify teachers'

Table C: Characteristics of focal teachers.

	School	Grade Level			Years Teaching at Start of Study
		Year 1	Year 2	Year 3	
Sarah	School E	1st	1st	1st	7
Kathy	School E	2nd	2nd	3rd	4
Xandria	School F	1st	1st	2nd	1
Nina	School F	1st	1st	K	9
Laura	School F	2nd	2nd	1st	3
Don	School F	5th	5th	5th	4.5
Florence	School G	K	K	K	25
Winona	School G	2nd	K	K	6
Larissa	School G	2nd	3rd	3rd	1
Tara	School G	4th	4th	5th	4
Denise	School H	5th	5th	5th	7
Quinn	School H	4th	4th	4th	7

attitudes toward the curriculum, we checked this information from teacher interviews in year 1 and using several questions on a teacher survey administered in year 2 of the study. This data confirmed that our sample included teachers with a range of attitudes toward the curriculum.[15]

Two of the original 14 teachers left their schools during the three years of the study. Both were new teachers in year 1 and, like many new teachers (Johnson, Berg and Donaldson 2005), decided to leave the profession after a few years of teaching. We compared the networks of the three remaining new teachers (those with three or fewer years teaching in year 1) to those of experienced teachers to see if the loss of two out of five new teachers in our sample influenced our findings. New teachers, on average, had smaller, less diverse but more expert networks in year 1. Their networks expanded and became more and became more diverse than those of experienced teachers in year 2, suggesting that they benefitted more from the expansion of the district mathematics initiative. By year 3, new teachers had networks that were quite similar to those of experienced teachers on all three network dimensions. This suggests that the attrition of two new teachers may have muted the overall rise and fall pattern that we note in our analysis.

For this article, we included only the 12 teachers for whom we have three years of data. See Appendix Table C for information about the 12 focal teachers.

Further information on the egocentric approach to social networks

A subset of this data collection was designed specifically to investigate focal teachers' social networks. We took an egocentric approach to social network analysis. In this approach, the analyst maps networks that are centered around an individual or social unit (the ego) (Wellman and Berkowitz 1988). To do this, we interviewed focal teachers individually, using questions designed to find out who a teacher talked with about mathematics instruction (both inside and outside of the school) and the frequency and content of their interaction, as well as why they talked with some people and not others. (See Appendix Table D for social network interview questions.)

The strength of the egocentric approach is that we did not make assumptions about the configuration of teachers' social networks but rather took identification of the networks as a first step for investigation. Because the analyst maps networks from the ground up using nominations solicited from the interviewees, the egocentric approach does not assume the locus of professional community is in formal structures such as grade-level groups or even exists within pre-existing boundaries such as the school (Carrasco et al. 2006; Reagans and McEvily 2003). In fact, all teachers except for one had networks that spanned beyond the boundaries of their school, which we were able to capture using the egocentric approach. However, the limitation of the egocentric approach is that because we did not do social network analysis with all teachers in the school (as one would with sociocentric approaches to network analysis), we are not able to map network structure for the entire school.

Further detail on social network measures

We mapped each of the 12 focal teachers' networks for each of the three years, drawing upon interview data to build egocentric networks. We then analyzed three

Table D: Social network interview questions.

Introductory script:
One of the things we're interested in learning about is how teachers talk with one another about mathematics instruction and how that makes a difference—or not—in what they do in their classroom.

1. In the last month, have you gone to anyone for advice, with a question or concern, or just to talk something through about *mathematics instruction*? If so, who have you gone to? Who else have you gone to? Anyone else inside the school? Anyone else outside of the school?

2. For each person mentioned, ask the following set of questions (go through complete set of questions for each person mentioned in turn):
   a. What role does that person play? [Are they a teacher? What grade? Something else?]
   b. Why do you go to some people and not others to talk about mathematics instruction?
   c. How frequently have you talked with this person about mathematics in the last month?
   d. What did you talk about?
   e. What advice, information did they offer? Can you give me an example?
   f. How, if at all, did this advice/conversation/talking with this person influence the way that you teach mathematics? Can you give me an example?

dimensions of the networks: network size, diversity of ties, and access to expertise. To analyze *size*, we counted the number of nodes in each teacher's network that were one step away from a focal teacher in a given year. To analyze the *diversity of ties*, we mapped each teacher's individual social network and analyzed the degree to which a teacher had ties that spanned different functional areas inside and outside the school. More specifically, we analyzed the degree to which ties were to others in a focal teacher's grade level, in other grade levels, to mathematics coaches, administrators, and to those outside the school. We then calculated the percentage of ties to others in areas beyond the focal teacher's grade level.

To analyze *access to expertise* in a network, we created a metric to assess the degree to which individuals in a teacher's social network had expertise, defined as having participated in prior professional learning opportunities related to mathematics. For example, individuals were considered to have high expertise if they had participated in four or more intensive professional development experiences. Intensive professional development was defined as sustained learning opportunities such as summer institutes that lasted more than a week or in-depth coaching. This did not include one-shot workshops or short-term experiences. Alternatively, someone with an undergraduate mathematics major or specialization in mathematics education in graduate work accompanied by two or more intensive professional development experiences was also considered to have high expertise. After evaluating the expertise of each individual in a focal teacher's network, we created an aggregate measure of the level of expertise in a given network by calculating the percentage of individuals in a network with moderate or high expertise.

To set a cut-point for a high level of expertise, we drew on existing studies of the prevalence of expertise in mathematics among elementary teachers. These studies suggest that mathematics expertise is rare in elementary schools, with no more than one-third of teachers in a given study having high levels of conceptual understanding (Ball 1990; Ma 2010; Post, Harel, Behr and Lesh 1991). Therefore, we considered teachers to have access to high levels of expertise if more than one-third of the individuals in their network had moderate or high expertise.

Next, we investigated the relationship between networks and the district mathematics policy. As part of this investigation, we analyzed the content of interaction: the nature of teachers' talk in social exchanges in their network. One dimension of the content of interaction we attended to is *depth of interaction*. To analyze depth, we identified 419 instances in our data where the 12 teachers in our sample interacted with others in their networks. We drew on research on teacher interaction (Coburn 2003; Little 1990) to develop criteria for assessing the depth of the content of interaction. Interaction was judged to be at low depth when it focused on surface structures or procedures, such as sharing materials, classroom organization, pacing, or how to use the curriculum. Interaction was judged to be at high depth when it addressed underlying pedagogical principles, the nature of the mathematics, or how students learn. Prior studies of public schooling suggest that interaction that we consider to be moderate or high depth—issues of mathematics teaching and learning or the nature of mathematics—is counter-normative (Little 1990; Lortie 1975) and rare (Sun et al. 2011). Instead, teachers are more likely to engage in quick assurances, exchanges of stories, and exchange of

activities or materials (Little 1990)—all forms of interaction that were coded as low depth in our study. Because prior studies suggest that high-depth interaction is rare, we characterized teachers' social networks as high depth if at least one-third of interactions that teachers had with others in their networks was about content judged to be of moderate or high depth.

Additional information about inter-rater agreement

To establish inter-rater agreement on social network measures, we randomly sampled 20% of social network data. Researchers coded the data separately and then calculated inter-rater agreement. We obtained inter-rater agreement for depth of content of interaction for 91% of data and for expertise of alters at 81% for an average of 86%. Importantly, most of the coding errors resulted from the difficulty of distinguishing moderate depth from high and moderate expertise from high. In the analysis for this paper, we combined these levels together, making this distinction irrelevant. If we combine moderate and high together for the analysis of inter-rater reliability, it increases to 96% for depth of interaction and 94% for expertise. A single analyst coded the remainder of the data, although coders met biweekly throughout the coding process to discuss challenging or ambiguous data, working together until consensus was achieved on the appropriate code to assign.

Additional information on techniques used to confirm findings

Because this study investigates the relationship between district policy and social networks in a single district, we could not rely on a cross-case comparison to draw inferences about the role of district policy. Instead, we relied on comparison of the state of teachers' social networks across three years, each of which had different policy conditions. We used a strategy called ''tracing a conditional path'' developed by Strauss and Corbin (1990) where the analyst systematically arrays the contextual conditions that cluster and co-vary as action unfolds, charting patterns of change over time. We also employed three additional strategies to guard against bias and bolster the analysis. First, we triangulated by collecting multiple kinds of data (interviews, observations, and documents) from individuals in different roles (focal teachers, nonfocal teachers, coaches, school administrators, district administrators), and analyzing these distinct data sources to generate the database of 419 teacher interactions. Drawing upon interviews from multiple people as well as observations and documents helped us capture a more complete picture of teacher interactions with those in their networks and provided a check against potential bias from using a single source. Second, we examined outliers for each of the patterns observed, in many cases returning to interviews or observations to understand teachers whose patterns did not match the overall trend. Third, we sought disconfirming evidence through the use of matrices (Miles and Huberman 1994). That is, we created summarized versions of data in table form, which then allowed us to check for disconfirming evidence across teachers. Lastly, we identified possible alternative explanations for the patterns we identified. We then performed further analysis to investigate whether the data supported these alternative explanations, ruling them out if it did not and incorporating the new analysis into our explanations if it did.

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NOTES

1. The names of the district, schools, and individuals are pseudonyms.
2. Schools E, F, and G had two half-time mathematics coaches each; School H had three.
3. Spillane (2005) provides evidence that teachers' social networks can vary substantially by subject matter. For this reason, we specifically asked about teachers' ties in mathematics rather than asking whom they interacted with more generally.
4. This finding was unexpected, since we purposely sampled schools with different levels of human and social capital. However, studies of teachers' classroom practice have consistently found greater

variability within school than between school (e.g., Hamilton et al. 2008; Rowan and Correnti 2008). Our study raises the possibility that there can also be greater variability within school than between in teachers' social networks.

5. All focal teachers except one went to individuals outside of the school for advice about mathematics. Ties outside of the school tended to be with relatives, teachers in other schools met in university classes or district-facilitated professional development, or district personnel. Like the networks more broadly, these ties had a rise and fall pattern across the three years (see Table 1). Ties to outside contacts tended to be more expert than within-school ties in year 1 but less expert in years 2 and 3. This may be because focal teachers had more ties to teachers outside the school (often fostered by cross-district activities) rather than district personnel in years 2 and 3; teachers tended to have less expertise than district mathematics personnel.
6. Rivera and his colleagues (2010) argue that researchers tend to investigate one of three explanations for tie formation: (1) assortive explanations, which emphasize tie formation as resulting from similarities and complementarities of actors' attributes; (2) relational explanations, which emphasize structuralist assumptions about the degree to which trust or information is conferred through an actor's position in a social network; and (3) proximity explanations, which emphasize how social interaction is arrayed in time and space. In our study, we identified factors associated with tie formation and maintenance inductively by analyzing interview data. The factors that emerged emphasized assortive factors (homophily, expertise) and proximity, rather than relational factors. One relational factor—prior relationships—did emerge in teachers' explanations, but it accounted for only 5 percent of ties in year 1, 2 percent in year 2, and 5 percent in year 3. (This factor is folded into ''other'' in Figure 1.) It is possible that there are other relational predictors of tie formation that might not emerge in teachers' own accounts. Prior research suggests that reciprocity, centrality, and the presence of third-party ties predict tie formation (Burt 2000; Powell et al. 2005; Rivera et al. 2010). However, we are unable to test reciprocity or the presence of third-party ties because of limitations in our data set; we did not measure reciprocal ties and have too much missing data to comfortably investigate third-party ties. We did investigate the premise that centrality predicts tie formation. The argument here is that people with large numbers of ties are more attractive to others, thus encouraging the development of even more ties (Brass, Forthcoming). However, we found that network size in one year did not predict network size the subsequent year. Thus, we found that relational factors such as prior relationships or centrality did not play a consequential role in tie formation.
7. It is possible that rather than being related to changes in district policy, the expansion and contraction of teachers' networks were a function of the natural life course of help-seeking in response to new innovation. In this scenario, teachers need increased assistance when faced with a new reform, so they reach out to others. Once they have ''mastered'' the innovation, they reach out less often. However, if this explanation accounted for the rise and fall of teachers' social networks, we would expect to see three things: (1) the largest networks during the first year when teachers were first confronted with the new curriculum; (2) a decrease across the three years in the degree to which teachers sought out others because of expertise, since they no longer needed others' expertise to implement the curriculum; and (3) an increase in reports that teachers did not reach out to others because they did not need assistance. We saw none of these things. Social networks were smallest during year 1, smaller even than after the networks declined again in year 3. The degree to which teachers sought out others because they saw them as having expertise increased over time. Finally, we analyzed whether teachers reported that they did not need assistance because they were comfortable or familiar with the curriculum (what we called ''self-assessment of expertise''). We coded only one instance of this in year 2; in year 3, the same teacher reported that she went to others because they had expertise. This evidence suggests that the expansion and contraction of the networks were not primarily the result of the ''natural life course'' of a new innovation.
8. An alternative explanation is that teachers in School G did not seek out others for reasons of expertise because there was no one in the school with expertise. Indeed, School G was selected because it had low human and social capital. However, our analysis suggests that there were multiple teachers with expertise in teachers' networks; three of the four teachers in the school simply did not recognize that expertise. Similarly, if school-wide level of expertise were a factor in the degree to which teachers sought out others for reasons of expertise, we would also expect to see limited advice seeking related to expertise in School E—the school selected for low human capital and high social capital. We did not.
9. In year 1, teachers identified only two people with expertise, both of whom were coaches. All coaches in our sample had moderate or high expertise, which is why the figure is 100 percent.
10. An alternative explanation for the increase in expertise is that people in teachers' networks increased

their level of expertise from year 2 to year 3. However, we found that only one individual was in focal teachers' networks across both years *and* had increased expertise from year 2 to 3.

11. The other two teachers in School G engaged in routines of interaction with their coach and colleagues at high levels in all three years.
12. It is possible that the increase in the percentage of routines in teacher-teacher interaction in year 3 is an artifact of the decrease in routines in coach-teacher interaction. To investigate this possibility, we analyzed the presence of district-designed routines in teacher-teacher interaction relative to all teacher-teacher interaction. If the increase in routines in teacher-teacher interaction were solely due to the decline in coach-teacher interaction, we would expect that the percentage of district-designed routines relative to all teacher-teacher interaction would remain flat. Instead, district-designed routines were present in just over 11 percent of teacher-teacher interaction in year 1, rising to nearly 40 percent in year 2, and then settling into 27 percent of teacher-teacher interaction in year 3.
13. We added four additional teachers to our sample from School H in year 2, as well as two additional teachers in each of the other schools. These teachers are not included in the present article because we include only those for whom we have three years of data.
14. Because we only have two teachers from School H in the study, there was less variability in grade represented: both teachers were from intermediate grades. We found no differences in teachers' social networks by grade level, so it is not likely that the omission of teachers from primary grades from School H affected our findings.
15. For more on the survey, see Coburn and Russell 2008.

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