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What is a "Good" Social Network for a System?: The Flow of Know-How for Organizational Change

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Abstract

This study concerns how intra-organizational networks affect the implementation of policies and practices in organizations. In particular, we attend to the role of the informal subgroup or clique in cultivating and distributing locally adapted and integrated knowledge, or know-how. We develop two hypotheses based on the importance of intra-organizational coordination for an organization’s capacity for change. The first emphasizes the importance of distributing know-how evenly *to* potential recipient subgroups. The second emphasizes the importance of restricting know-how to flow from high know-how subgroups. We test our hypotheses with longitudinal network data in 21 schools, finding stronger support for the second hypothesis than the first. Our findings can help managers cultivate know-how flows to contribute to organizational change.

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The Flow of Know-How for Organizational Change

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INTRODUCTION

Implementation research focuses on how practice shapes the effects of policies (Berman & McLaughlin, 1975; Cohen, Moffitt, & Goldin, 2007; Majone & Wildavsky, 1977; Werner, 2004). In the 1960s, implementation research focused principally on whether policies were implemented as intended. But beginning in the 1970s, implementation researchers began to document what practitioners know that policy makers cannot and how practitioners use that know-how to change policy in practice. Implementation research began to focus as well on the concerted efforts of local implementers to make sense of policies through social interaction that shaped individuals' decisions about how to respond to new policies (Weick, 1995; Weick, Sutcliffe, & Obstfeld, 2005).

In the example in this study concerning educational policies, implementation is especially dependent on the collective sensemaking of school personnel. Sensemaking is critical because high level policy, at least historically, is only loosely coupled to classroom practice (Bidwell, 1965; Meyer & Rowan, 1977; Weick, 1976). We recognize that in the past decade accountability systems have tightened the relation between policy and practice

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by incentivizing new forms of coordination and collaboration among teachers and administrators to share know-how that can improve student outcomes (Spillane, Parise, & Sherer, 2011). But even in this context, “learning supports” that include opportunities for teachers to interact with one another are key for teachers to implement new policies and programs (e.g., Cohen & Hill, 2001).

Though past research has pointed to the importance of facilitating interaction among those who possess diverse forms of know-how (Schumpeter, 1934) and on reducing transaction costs among dependent actors with common social contexts and cognitive schema (Williamson, 1981), the structure and nature of interactions required to support policy implementation is not well understood. Some accounts privilege the density of interactions among individuals as an ideal, but maximizing interactions heightens transaction costs associated with maintaining the network (Hislop, 2005). Other accounts stress the importance of linkages between informal subgroups or cliques in which interactions are concentrated, but do not specify which bridges are best to build. With respect to what kinds of social interactions support policy implementation, “What is a good network?” is at least partly an open question.

Example: The School as a Social System

The implementation of innovations in schools has proven vexing for reformers and organizational theorists alike (Elmore, Peterson, and McCarthey 1996; Tyack and Cuban 1995). Part of the challenge is due to the importance of local networks on teachers’ practices (e.g., Bidwell, 2000, 2001). This creates variability in practices that cannot be explained easily by factors external to a school. In this way schools are similar to other organizations whose workers draw on networks to adapt innovations to local contexts (Bidwell and Kasarda, 1987).

Perhaps it is the importance of informal processes in schools that has prompted organizational theorists to give considerable attention to schools (Bidwell and Kasarda, 1987; Bolman and Heller, 1995; Perrow, 1986). In particular, schools have been used in the development of theories of organizational control (Callahan, 1962), contingency (e.g., Greenfield, 1975), new institutionalism (Meyer and Rowan, 1977; Rowan, 1995) and social capital (Bryk and Schneider, 2002; Spillane et al., 2003; Leana and Pil, 2006; Frank, Zhao and Borman, 2004). We will return to this thread too discuss how our findings relate to other organizations.

Some have taken the importance of the school as a social institution to focus on educational and policy issues of curriculum (e.g., Schmidt et al., 2011), academic tracking (e.g., Gamoran, 1987; Oakes 1985), or testing (e.g., Hanushek and Raymond, 2005). But these foci do not attend to the internal social dynamics of schools, especially of the school faculty (Bidwell, 2000, 2001). Such dynamics can have direct effects on teachers’ practices which are the primary work activities in schools (e.g., Cohen, Raudenbush and Ball, 2003; O'Day, 2002).

In this study, we draw on the literature in business and management as well as sociology to relate the internal social dynamics of the school personnel to the capacity of the school to implement changes. In particular, we attend to the importance of emergent subgroups of teachers as teams (Marschak and Radner, 1972; Reagans and Zuckerman, 2001; Reagans and McEvily 2003) that can locally adapt and integrate knowledge, creating what we refer to as know-how. In turn, this know-how can be used by others members of their organization (e.g., Hansen, 1999; Nahapiet and Ghoshal, 1998; Nonaka, 1994; Szulanski, 1996; Von Hippel, 1994).

Anticipating our key results, we find that the more know-how flows *from* a restricted set of subgroups, the greater the organizational change. In particular, schools are better able to implement changes when only a few subgroups in the school are responsible for providing know-how to the rest of the school. In contrast, there is no effect of the dispersion of know-how flows *to* potential receiving subgroups on organizational change. Schools can implement innovations to some degree even when some subgroups have more access to know-how than others. This provides an initial glimpse into the relationships between the flow of know-how and organizational change.

In the next section we describe the organizational context in which know-how is created within subgroups and then flows between subgroups. We then describe how we quantified the potential for know-how to flow and how we tested our hypotheses using longitudinal social network data in 21 schools engaged in whole-school reform efforts (e.g., including literacy, technology integration, using data to guide improvements to instruction). We then present our results, including descriptive statistics, regression analyses, graphical representations and sensitivity analyses. We discuss our results in terms of the flows of know-how through social structures, implications for other organizations, the role of the manager and we identify limitations.

BACKGROUND

The Organizational Context of the Flow of Know-How

The flow of know-how is important in organizations such as schools which rely on complex production involving extensive coordination, extensive local adaptation, or both (Simon, 1965; Thompson, 1967; Williamson, 1981; Woodward, 1965). In schools, the complexity is due to multiple forces: variability in student needs, which can influence decisions about what and how to teach (e.g., Barr and Dreeben 1983; Delpit 1988); conflicts among organizational demands that arise from policies enacted at different levels of organization (e.g., Bidwell and Kasarda 1987; Honig, 2006); varying levels of coherence among curriculum, pedagogy, and assessments (Borman et al. 2003; Schmidt 2001); and from teachers’ unique educational trajectories, which exposes them to varying educational approaches (Lortie 1975; Coburn, 2004). As a result, teaching is complex because teachers must both adapt practices to local contexts and coordinate with each other as they do so (Bidwell, 1965; Thompson, 1967; Woodward, 1965; Zhao and Frank 2003).

Consider the teacher below describing a routine of explanation concerning the implementation of a new pedagogy (Coburn and Russell 2008, page 218):

> We talked about, like, the math message and the mental math and how to coordinate the two and that we should be linking the message to the initial onset of the mini lesson and how those two are connected and that that would get the children eventually into their individual work and that we should connect them and that the math messages is separated from the mental math after it’s done until we go back to it and use that as a lead in for the lesson.

Note that the new approach, math message, must be coordinated with the old, mental math, creating a locally defined complex task. The complex task is then articulated and know-how shared through the teachers’ talk pertaining to how to implement the new approach, motivate the children, differentiate the approaches, and structure the lesson. Each of these tasks depends on the local context defined by the students, curricula, and organizational context, which in this case included a math coach to whom the teacher was describing her interactions. Consistent with the quote above (Coburn and Russell, 2008), the know-how teachers access from one another has been shown to be essential for implementation of computer technology and schoolwide reforms into teachers’ classroom practice (e.g., Frank, Zhao and Borman, 2004; Frank et al., 2013; Frank et al., 2011; Penuel et al., 2012; Penuel et al, 2007).

Diffusion at the Level of the Social System

In this study, we extend the above findings from individual teachers to the level of the organization by analyzing how interactions are shaped by subgroups. Here we define subgroups by their concentrations of interactions among a set of actors. Less formally, subgroups can be thought of as cliques. Within subgroups, dense interactions support knowledge sharing and norms that are likely to create relatively homogenous action (Nonaka, 1994; Yasumoto, Uekawa, and Bidwell, 2001). Therefore, we focus on interactions *between* subgroups which more likely contribute to variation in the practices related to the implementation of an innovation. .

To gain intuition about how subgroups can shape diffusion within an organization, consider Frank and Zhao’s (2005) graphical representations of the diffusion of teachers’ use of technology through the intra-school networks in Westville School. Frank and Zhao began by representing the social structure of close collegial ties (in response to the question: “who are your closest colleagues in this school?”) within cohesive subgroups as in the crystallized sociogram Figure 1. In Figure 1, each number represents a teacher or administrator, and the text following the number indicates the grade in which the teacher teaches (e.g., G3 indicates grade 3, MG indicates multiple grades, and GX indicates unknown grade). The subgroup boundaries were identified by Frank’s (1995, 1996) KliqueFinder algorithm and are represented by circles around subsets of school personnel. The lines connecting pairs of personnel indicate that at least one member of the pair listed the other as a close colleague (solid lines within subgroups, dotted lines between subgroups).

Insert Figure 1 about here

The social structure represented in Figure 1 can be used to characterize the diffusion of an innovation such as implementation of technology in the classroom. Just before the data in Figure 1 were collected, Westville’s school district switched from the Macintosh to the Windows platform. This created an organizational challenge for the school which did not have much expertise in Windows. As an initial response, school administrators secured the re-assignment of teacher 2, an expert in Windows, to Westville.

The challenge for the school was then to circulate teacher 2’s know-how. To understand how teacher 2’s know-how flowed, consider Frank and Zhao’s (2005) Figure 2. In this Figure actors and subgroups are located based on the pattern of close collegial ties in Figure 1. But the lines now indicate talk and help with technology between time 1 (spring 2000) and time 2 (spring 2001). Furthermore, each actor’s identification number has been replaced with a dot proportional to his or her use of technology in the classroom at time 1 (an * indicates no information available). The ripples then represent increases in the use of technology from time 1 to time 2, with each ring corresponding to an increase of .2 standardized units.

Insert Figure 2 about here

Figure 2 shows how teacher 2’s know-how flowed first among the dense concentration of close collegial ties within subgroup B, then to subgroup C through a specific bridging tie formed between teacher 2 and teacher 20, and then through teacher 20 to subgroup A. [1] Teacher 20’s interactions with members of subgroup A were then associated with large changes in their implementation of technology (as indicated by ripples around the three teachers who received help from teacher 20). This emphasizes the value of resource flows that bridge between subgroups for an organization’s capacity for change (Burt, 2005; Tsai, 2001).

Generating Hypotheses: Bridges to Where?

The previous analysis raises the question: From the system perspective, once a tie crosses the subgroup boundary, with which others should it optimally form to support an organization’s capacity for change? Should the ties between subgroups be uniformly distributed? If they should be targeted, on what basis?

We develop two hypotheses, each of which stems from the fundamental dynamic of classroom learning. In particular, learning is more effective when learners encounter a

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[1] While the diffusion of know-how throughout Westville elementary may appear a success, the organization was in fact extremely challenged because of its social structure. In particular, note that there were no close collegial ties between subgroup B containing most of the second grade teachers and subgroup A containing most of the third grade teachers. This subdivision reflected the history of the school – it was consolidated from two previous schools, with grade 2 teachers coming from one school and grade 3 teachers from another. Furthermore, the grades were assigned, for the most part, to separate wings of the school.

The lack of collegial ties between subgroups A and B created severe coordination challenges for the teachers which in turn created challenges for the students, especially as they transitioned from grade 2 to 3. It also created competition for resources. Although the challenges were overcome in the particular case of technology implementation via the bridging ties of actor 20, in general these challenges were not overcome, and Westville was reconfigured (to include only first grade) shortly after the time the data in Figures 1 and 2 were collected. This highlights the role of the organization in structuring the flow of resources which can ultimately be related to survival.

coordinated set of teaching practices that is coherent with respect to instructional aims and strategies (e.g., Newmann, Smith, Allensworth, & Bryk, 2001). This allows understanding to build over time, and in relation to core ideas and practices in disciplines taught in school (e.g., National Research Council, 2007).

Because schools in the U.S. rarely are able to rely on hierarchical control of teaching practices, teachers may have to informally communicate to coordinate. To do so, teachers will need to access comparable levels of know-how they can draw on as a basis of communication (Hansen, 1999; Szulansk, 1996) and to implement changes in practices (Bill & Melinda Gates Foundation, 2012; Sun et al., 2013). In addition, teachers have limited time to communicate about the details of their teaching; their descriptions of practice are often synoptic rather than elaborated (Little, 2003). As a consequence, communication and coordination is easier when teachers’ descriptions of practice are easily interpretable, because they signal shared beliefs and approaches to teaching, as well as shared taken-for-granted contexts. We would expect that communication and coordination would be difficult between subgroups of teachers immersed in the language and practices of different approaches to instruction, such as phonics-based basic skills instruction versus balanced literacy instruction, or between subgroups of teachers whose teaching context is so different that miscommunication is likely when speaking about practice in synoptic ways.

The preceding logic implies that at the level of an organization such as a school, the efficiencies of coordination will be realized when each subgroup has equal access to sources of know-how. Otherwise those subgroups that do not have access to the requisite know-how will encounter difficulties in communicating about and implementing new practices, decreasing the overall level of implementation of an innovation. This leads to the following formal hypothesis:

H_1: The more *even* the flow of know-how *to* potential recipient subgroups the greater will be the systemic implementation of practices dependent on the know-how.

Our second hypothesis focuses on a different basis for coordination. In particular, coordination may be achieved by limiting the number of intra-organizational sources that influence teaching (Bidwell and Quiroz, 1991; Tsai, 2001). For formal governance this limitation implies an oligarchy. But when locally adaptive practices are not easily formally controlled, the limitation implies a restriction on the informal sources that provide the know-how workers are likely to draw on to change their practices. The fewer sources that provide local know-how, the more members of the organization will access similar know-how, allowing them to communicate and coordinate their practices. All else being equal, it is better for one subgroup to provide know-how to three other subgroups than for three different subgroups to provide the know-how separately to each subgroup. Therefore our hypothesis relates the flow of know-how *from* high-level implementers to organizational change. Formally:

H_2: The more know-how is *restricted* to flow *from* subgroups with high levels of know-how, the greater will be the systemic implementation of practices dependent on that know-how.

This hypothesis relates to the general value of specialized units for creating knowledge (Tsai, 2001). But in this case we emphasize that the units are emergent, and not formally defined. Moreover, we identify their value as their capacity to insure the flow of high-quality and consistent know-how to other subgroups in the system.

Hypotheses 1 and 2 represent different conceptualizations of know-how. The first hypothesis is based on the assumption that know-how can be accumulated in separate units and then implemented by any subgroup accessing adequate know-how. The second is based on the assumption that there may be a qualitative difference between the know-how that can be provided by a high implementing subgroup versus the same number of units of know-how provided by separate subgroups. In the discussion we will return to these conceptualizations.

METHODS

Our methods section begins with a description of the collection of data from individual teachers in 23 schools. The measures include sociometric items asking teachers to list their closest colleagues. We then describe how we identified subgroups in each school from these data. We then describe the measures we created of the potential flow of know-how from teachers’ responses to questions about their implementation of their school-wide initiatives and to questions about from whom they get help regarding implementation of their school-wide initiatives. We present an analytical plan of regressing school-wide change in the initiative on the measures of potential flow of know-how, and we explore covariates. We also describe the graphical representations and sensitivity analyses we conducted.

Sample

We began with a sample of school staff from 23 mostly elementary schools from a single state in the U.S. Pacific West region. [2] Our sampling criteria increased the probability we would observe how teachers’ interactions affected their implementation of new practices related to the initiative. In particular, we sought to include schools that (1) were engaged in a reform initiative intended to have a school-wide influence on teachers’ practices and (2) had distributed leadership across people and practices (Spillane, 2006), evidenced by assignment of responsibility for the initiative to multiple actors in the school and by allocation of time for teachers to meet regularly to discuss their school’s initiative.

The school-wide initiatives focused on a variety of different areas. The most common focus was on the improvement of literacy instruction (*n* = 5). Other schools foci included integrating technology into instruction (*n* = 4), improving the use of data to inform instruction (*n* = 3), and fostering social and emotional development of students (*n* = 2). See Penuel et al., (2009) for further description of the school-wide initiatives.

In all but one case, the school-wide initiatives were defined at the school or district level, rather than by a national whole-school reform model, although several local school-wide initiatives were adapted from national models (Coburn, 2005). Such locally defined school-wide initiatives are the most common type of school reform, and also the most problematic with respect to implementation (Datnow and Stringfield, 2000). From a theoretical standpoint, we viewed the diversity of these initiatives as an important resource for generating robust theory.

We present the basic demographics for our schools in Table 1. Our sample of schools is both similar to and different from the schools in the state as a whole. The sample

[2] There were 12 elementary schools; 3 kindergarten through 8 schools; 3 middle schools; one 7-12 grade school; and two high schools.

is similar in that it includes schools with a significant percentage of students who are eligible for free and reduced price lunch and many schools with high levels of racial diversity. Overall, the percentages of students eligible for free and reduced price lunches is slightly lower (12%) than the state average for schools, and sample schools have slightly higher (12%) percentages of White students than the state as a whole. But the differences are modest, and our model of change in implementation controls for any characteristic of the school that was fixed over time (see analytic strategy below).

Insert Table 1 about here

Procedures

We administered a questionnaire to all staff with responsibilities for classroom teaching in fall 2004 (time 1) and again in spring 2005 (time 2). The survey included sociometric items asking staff to indicate the others in the school whom they considered close colleagues and who helped them implement the school-wide initiative. At each time point, respondents also indicated how explicit they perceived the school-wide initiative to be, how much the specific initiative had influenced their teaching practice, and how much normative pressure they felt to implement the initiative in their classroom.

Teachers typically completed the survey in 20 to 30 minutes during a faculty meeting. We provided an administrative assistant at the school with a postage-paid return envelope for teachers who did not complete the survey when the researcher was on-site. In addition, we provided an incentive to each school for a high response rate. The average response rate within each school was 83.6% in fall 2004, and 80.4% in spring 2005 (with a range across schools from 62% to 94% and a median of 85%).

As indicated in Table 2, more than three-quarters of the respondents were female and more than three-quarters of those surveyed were white, and the vast majority of faculty members held a clear teaching credential (not an emergency or provisional credential). These are consistent with national trends (United States Department of Labor, 2011). Consistent with the ratio of elementary to secondary schools in the sample, the majority of teachers taught at the elementary level. In addition to the statistics presented in Table 2, on average, teachers in the sample reported having 13 years of classroom teaching experience (standard deviation of 10), including 6.7 years (standard deviation of 6.6) at their current school, and the median class size was 22 students.

Insert Table 2 Here

Dependent Variable: School Level Implementation of New Initiatives

Our primary dependent variable is based on responses to how the local school-wide initiative affected the respondents’ teaching practices. These practices included the curricular materials used, instructional strategies and activities, assessment strategies, standards and topics covered, performance levels expected of students, complexity of work assigned, classroom management techniques, student grouping methods, professional development sought, and roles and responsibilities of students and teachers for learning (adapted from Bodilly, 1998). These are the core professional practices of teaching. Teachers indicated whether they engaged in a practice or not, were not sure, or that the practice was not targeted by the school-wide initiative. The dependent variable was defined by the total number of practices which a teacher indicated were affected by the initiative ($\alpha = .92$). After computing the change in a teacher’s responses between time 1 and time 2, the final dependent measure was defined as the mean change score for the teachers in a given school.

Independent Variable: Measure of Entropy

Intuition. To test our hypotheses, we developed measures of the potential flows of resources, such as know-how, through networks. Economists and demographers have generated extensive measures of the distribution of resources in social systems (e.g., Gini, 1921; Reardon and Firebaugh, 2002), but these measures are not directly functions of the network structure through which resources flow. On the other hand, the social networks literature contains extensive measures of the social structure of a system such as in terms of centralization (e.g., Freeman 1978/1979; Wasserman and Faust, 1994). But the measures do not account for the location of specific resources in a network and therefore cannot relate the potential flows of specific resources to systemic change.

Closer to our goal, Touvet and Harle (2001) and Bonachich and Bieninstock (2003) examined structural characteristics of networks and the potential for resource flow. Similarly, Ingram and Roberts (2000), Reagans and Zuckerman (2001), Reagans, McEvily and Zuckerman (2004), Tsai (2001) and Yayavaram and Ahuja (2008) infer a link between network structure and organizational performance. But these approaches do not directly relate organizational change to the potential for resource flow through network structure. Instead they relate a static distribution of resources to organizational change or reduce to explanations of resource flow in terms of patterns in the social structure but not the location of resources in that structure. [3]

To characterize the potential for resource flow through a social structure, we employ Shannon’s (1948) measures of entropy of communication, which were adapted from measures of

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[3] This critique even applies to Yayavaram and Ahuja’s (2008) measure of decomposability (page 351), which is based on the structure of the network (see also Provan and Milward, 1995).

entropy in the physical sciences. [4] Conceptually, Shannon’s entropy measures reflect the extent to which a resource such as know-how has the potential to flow evenly over possible links in a system. The more channels over which resources may flow, the greater the entropy in the system because there is less certainty about the link over which any given resource will flow.

The intuition behind Shannon’s measures is that one first converts potential flows into the probability that a resource will flow over a given link. These probabilities represent how flows are distributed independent of the absolute levels of flow. Each potential flow contributes to the overall measure of uncertainty inversely proportional to its probability – the smaller the probability, the larger the contribution. When accumulated across flows, many small probabilities translate into large values of uncertainty.(see technical appendix A for details).

Consider a hypothetical system in which there are only two links over which resources could flow as shown in Figure 3. If the probabilities of flow both equal .5, entropy is at its highest indicating maximum uncertainty over which link a resource will flow. Entropy then declines symmetrically as the difference in the probabilities increases. Thus entropy has intuitive appeal as a measure of the evenness of the flow over a network; it is highest when a resource potentially flows evenly across possible links and declines as potential flow becomes concentrated over particular links.

Insert Figure 3 Here

While Shannon’s measure of uncertainty has clear value for communications engineers (Verdu, 1998), it has also been used to characterize the distribution of the flow

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4 Shannon used the term entropy to relate his measures to Boltzmann's statistics from thermodynamics, which characterized the disorder of molecules.

of resources in other systems, such as ecosystems (e.g., McCann, 2000; Ulanowicz, 1997; Zorach and Ulanowicz, 2003). In the sociology and business literature, Burt (1998, 2000) traces his measures of constraint through Coleman (1964) to Shannon's indices. Relatively recently, Reardon and O'Sullivan (2004) argued that measures of entropy are especially valuable for their flexibility, ability to handle transfer (movements of individuals in the social space), their scale-free quality, and their theoretical motivation from communications. Furthermore, Dionisio, Menezes, and Mendes (2006) argued that Shannon's measures have several desirable properties, relative to variance, to characterize dispersion or diversity in probabilities of flows. Given the advantages of measures of entropy for characterizing resource flow through networks, we *rephrase* our hypotheses relating potential resource flows to organizational change in terms of the evenness of the distribution of know-how (entropy):

H_1 [restated in terms of entropy]: The *greater* the entropy of the flow of know-how *to* subgroups the greater will be the systemic implementation of behaviors dependent on that know-how; and

H_2 [restated in terms of entropy]: The *less* the entropy of potential flow of know-how *from* subgroups the greater will be the systemic implementation of behaviors dependent on that know-how.

Formal measure of entropy. Our key independent measures of entropy were functions of two types of information from the surveys: interaction among teachers, and each teacher's report of how much they implemented the school-wide initiative at time 1 – the more the teacher implemented the school-wide initiative at time 1, the greater was the teacher’s know-how that could be transmitted to others. We measured the interaction through which know-how could flow from the question asking teachers to indicate who had helped them in the past twelve months implement their primary school-wide initiative. We also asked teachers to indicate the frequency of interaction with each provider of help -- once or twice a year, monthly, weekly, daily. To approximate an interval scale we coded these according to their meaning in the context of the typical school calendar. The calendar covers 9 months, roughly 40 weeks, and roughly 160 days. Therefore the coding was once or twice a year = 1, monthly = 9, weekly = 40, daily = 160.

Following previous research (Penuel et al., 2009; Frank Zhao and Borman, 2004, Zhao and Frank 2003), know-how is conceptualized in terms of the sets of practices teachers use to implement particular reforms (e.g., Barley & Kunda, 2001; Brown and Duguid, 1991). This know-how is specific to the school-wide initiative, and does not necessarily apply to other aspects of teaching. For example if a school-wide initiative focused on language arts, then know-how refers to how to implement the initiative in language arts instruction, and would be independent of mathematics instruction.

Formally, let $w_{i,i'}$ represent the potential flow of know-how as the product of the frequency of help provided by teacher *i’* to teacher *i* between time 1 and 2 and the know-how of teacher *i’* at time 1. For example, if Bob received help implementing a school-wide initiative weekly (40 times in the past school year) from Jane, and Jane had implemented 6 aspects of the school-wide initiative in her practices one year ago, then Bob’s potential access to know-how through help received from Jane would be: $w_{Bob,\ Jane}$ = 40 x 6 = 240.

Given our focus on bridging ties, we attend to the *variation* in the flow of know-how *between* subgroups (Hansen 1999; Reagans and McEvily, 2003; Reagans, McEvily and Zuckerman, 2004; Reagans and Zuckerman, 2001; Burt, 1992; Yayavaram and Ahuja, 2008). The measure of the flow of know-how between subgroups A and B, $w_{A,B}$, is the sum of the $w_{i,i'}$ between members of subgroups A and B, where subgroup A contains members who received help from members of subgroup B. Continuing the previous example, assume Jane and Bob are in different subgroups and Jane is the only member of her subgroup who helps members of Bob’s subgroup. If Jane helps only one other member of Bob’s subgroup 10 times a year then flow from Jane’s subgroup to Bob’s is 40 x 6 + 10 x 6 = 300.

The key to Shannon’s approach for defining a system level measure is to transform absolute levels of flow as in $w_{A,B}$ to characterize the distribution of flow in terms of the probability, p(*A*,*B*), of flow over a given link:

$$p(A,B) = \frac{w_{A,B}}{\sum_{A,B} w_{A,B}} \text{ . (1)}$$

Thus p(A,B) represents the probability that any given flow will occur over the AB link.

Drawing on Shannon’s approach, p(A,B) can be used to characterize the evenness of flow across a system (see the technical appendix A for details and further motivation). First, the probabilities are transformed according to: [5]

$$p^*(A,B) = -p(A,B)Ln[p(A,B)] \text{ . (2)}$$

The $p^*(A,B)$ are then summed to construct the measure of entropy:

[5] Although Shannon's equations were base 2 logarithm units, we chose the natural logarithm as a base, which does not change any of the patterns in our theoretical examples or empirical results.

$$E = \sum_{A}^{n} \sum_{B}^{n} p^{*}(A, B) \text{ . (3)}$$

As shown in Figure 3, this entropy measure is at its peak when flow is equally likely over all links.

Shannon proves (Shannon, 1948, pages 10-11 and appendix 2) that the form in (3) multiplied by a constant, is the only form that is 1) a continuous function of p^*; 2) is a monotonic increasing function of the number of events of equal probability – entropy increases with an increasing number of possible events; and 3) can be decomposed into successive choices.

In technical appendix A we deconstruct the measure of entropy to separately represent the flow of resources *to* subgroups (hypothesis 1) from the flow of resources *from* subgroups (hypothesis 2). In particular, to construct the measure for flow *to* subgroups we first calculated the amount of help each subgroup received from others based on the sum of know-how received by that subgroup from all other subgroups. Call this $w_{.B}$. We then transformed the $w_{.B}$ to probabilities as in (1), converted to p x ln(p) as in (2) and summed across all potential receiver subgroups as in (3). We then used the feature that entropy increases monotonically with the number of possible events to standardize the measures against a maximum number of flows in each school. This is essential for evaluating the relationship between resource flow and systemic function *across different schools* as we do in the next section. Similar calculations were used to construct the measure of provider entropy, beginning by first measuring the amount of know-how each subgroup provided *to* others based on the sum of know-how provided by that subgroup to all other subgroups.

Covariates

We considered covariates that are likely related to change in implementation of school-wide initiatives, the distribution of know-how, or both.

Perceived explicitness of the school-wide initiative. Previous research has shown the more well specified an initiative is, the more likely it will be implemented (Cohen and Ball, 2001). Perceived explicitness of the initiative was measured from the school mean of teachers’ responses to the following items: there is an overall plan that specifies what teachers need to be doing in their classrooms in order to implement the school-wide initiative; there are clear assessment techniques that identify progress in implementing the school-wide initiative; the school-wide initiative is well specified; and most teachers know what they need to do for implementation (scale: 1=strongly disagree; 2=disagree; 3=agree; 4=strongly agree; Cronbach’s α=.87, items listed in order of correlation with the total).

Duration of the school-wide initiative. The distribution of know-how flows may be confounded with the duration of the school-wide initiative because the longer an initiative has been implemented the more potential sources of know-how there will be in the school. Therefore we considered a control for the duration of the initiative in years (1-7) as measured from principal reports.

Perceived pressure to implement the school-wide initiative. Initiatives may be more likely to be implemented if there is perceived pressure to do so, regardless of know-how flows (Burt, 2005; Frank, Zhoa and Borman 2004). Therefore, we examined how our estimates changed after controlling for perceived pressure to implement the initiative. The measure of perceived pressure to implement the school-wide initiative was based on the mean of teachers’ responses to the following items: most of the teachers in the school believe there is value in this school-wide initiative; and most of the teachers in the school would like to see the school-wide initiative continue (scale: 1=strongly disagree; 2=disagree; 3=agree; 4=strongly agree; the items were correlated at .79). Because perceived pressure may vary within the school, for example by subgroup membership, we calculated a measure for both the individual teacher and for the mean of the school.

School size. It may be that larger schools have more difficulty changing teaching practices than small schools, for example as teachers in small schools are more likely to share a sense of collective efficacy facilitating collaboration (Lee and Loeb, 2000). Therefore we explored controls for school size in terms of number of employed teachers.

Structure of the Network. The distribution of know-how may depend directly on the structure of a network. The most basic network measure is the density of ties, defined as the proportion of possible ties between pairs of actors that were realized. But know-how flows might also depend on the extent to which there is reciprocity (A→B; B→A) or transitivity (A→B, B→C, A→C) in a network. Reciprocity and transitivity are indicative of clustering (Davis, 1970), potentially isolating sources of know-how needed for implementation. Correspondingly, we also controlled for the extent to which ties were concentrated within subgroups versus between subgroups. We constructed measures of each aspect network structure for the closest colleague data used to define the subgroups as well as for the specific interactions about the school-wide initiatives.

Analytic Strategy

Following our theoretical focus on *between* subgroup interactions, the prologue for our analysis was to identify cohesive subgroups in which collegial relations were concentrated. We did so from the time 1 sociometric question regarding teacher’s closest colleagues, a stable and enduring relationship (Frank and Yasumoto, 1998; Frank and Zhao, 2005). Identifying subgroups within each school in our sample then required an algorithm that could identify non-overlapping cohesive subgroups with a minimum of subjective input or interpretation from the researcher (e.g., specification of the number of subgroups, criteria defining subgroups). We used Frank’s (1995, 1996) KliqueFinder network clustering algorithm for this purpose which has been employed in both the social sciences (e.g., Frank and Yasumoto, 1998; Frank and Zhao, 2005; Yasumoto, Uekawa, and Bidwell, 2001) and the natural sciences (e.g., Jaeger et al., 2010a, 2010b; Krause et al., 2003; Krause et al., 2010). The algorithm maximizes within subgroup density relative to between subgroup density. The criterion is also related to social network models such as exponential random graph models and p_2 (Frank 1995; Lazega and Van Duijn, 1997; Snijders et al., 2006; Wasserman and Pattison, 1996).

Ultimately, we identified 115 subgroups (with 10 teachers unassigned) across 23 schools, with the average subgroup containing 3 to 4 teachers who responded to the survey at time 1 and time 2 (subgroups contained other members who completed the time 1 sociometric questions but who did not complete the survey at time 2). We removed one school from our sample because the concentration of close collegial relationships within the subgroups was not great enough to reject a null hypothesis that there were no subgroups ($p > .05$, see Frank, 1995 for the Monte Carlo procedure and significance test for the presence of subgroups).

At the school level we then calculated descriptive statistics and correlations among our measures of entropy, and change in implementation of the initiative. To test our main hypotheses we regressed change in mean level of implementation of the initiative on the measures of entropy at the school level. For two time points of data using a dependent variable of change in behavior is equivalent to a fixed effects analysis and therefore controls for any characteristic of schools that were constant over time (Wooldridge, 2010). In technical appendix B we confirm our main estimates using a multilevel model of teachers nested within schools (Raudenbush and Bryk, 2002), but we present school level regressions because our hypotheses are specified at the organizational level. Furthermore, the descriptive analyses, graphical and sensitivity analyses we present below are more interpretable in terms of a single level model (see Seltzer, Frank and Kim, 2006, for the challenges in conducting our sensitivity analysis in multilevel models)[6].

Because of the small sample of schools we attended carefully to school level outliers and the distribution of residuals. In particular, we removed one school from our analysis because it had an inexplicably large decline in implementation (a value of -4 relative to a sample mean across all the schools of -.13 and standard deviation of 1.15 and the next lowest value was -1.45; including this school in our analyses roughly doubled the standard errors for all predictors using OLS or HLM and reduced the R^2 to zero); after removing this school, our final analytic sample included 425 school personnel in 21 schools. To interpret inferences from our models, we plotted

[6] See Raudenbush and Bryk’s (2002) discussion in chapters 3 and 5, in particular their comment (page 108) that a school level model yields unbiased estimates (although there may be some loss of efficiency relative to multilevel weighting according to sample size).

change in implementation against our measures of entropy. Finally, we quantified the robustness of our inference to potentially omitted confounding variables and sampling bias.

RESULTS

The Relationship between Entropy and Implementation of School-wide Initiatives

Table 3 shows the descriptive statistics for our dependent measure and our focal independent measures as well as the correlations among them. The mean change in implementation was positive (.056), but small relative to its standard deviation (.759). Thus some schools increased their implementation of school-wide initiatives while others stayed stable or decreased, reflecting the general difficulties in changing school behaviors on a large scale (e.g., Tyack and Cuban, 1995). Mean change in implementation was weakly correlated (and negative) with potential receiver entropy, but strongly negatively correlated (-.654) with potential provider entropy.

Insert Table 3 Here

Table 4 contains the results of the school level regression of mean change in implementation of the school-wide initiative on the measures of entropy. The coefficient for entropy of potential receivers was in the expected direction (hypothesis 1) but was smaller than its standard error. There was little evidence to reject a null hypothesis of no relationship between potential receiver entropy and implementation of the initiative. In contrast, hypothesis 2 was supported; the greater the entropy with respect to potential providers, the less the increase in implementation. The magnitude of the coefficient of −3.22 was more than three times its standard error of .86 (using multilevel models via SAS proc mixed as per Singer, the estimate was −3.11 with standard error 1.09 – see technical appendix B for details).

The results for model 2 show the estimated effect of potential provider entropy was only slightly smaller (.04 difference) when controlling for the empirically strongest covariate, the duration of the initiative; importantly, controlling for the duration of the initiative had no effect on our statistical or substantive inferences. The estimated effect of potential provider entropy was larger when controlling for each of the other school level covariates and the standard errors were larger (controlling for perceived pressure at the individual level, the estimated effect of potential provider entropy was slightly smaller, −3.08, but with 25% larger standard error, 1.18, and no change in inference). Therefore we use the more precise estimates in Table 4 as the basis for our preliminary inference that the more restricted the potential flow of know-how *from* subgroups with greater know-how, the greater was the implementation of the school-wide initiative.

Insert Table 4 Here

To evaluate whether the relationship between potential provider entropy and mean implementation of the school-wide initiative was roughly linear and systematic, consider the plot of each school’s change in implementation against potential provider entropy shown in Figure 4. The plot shows a clear linear relationship that cannot easily be attributed to a single outlier. Thus we take the regression estimate as indicative of a general, linear, trend.

Insert Figure 4 about here

The Robustness of our Inference

Concerns about Omitted Variables (Internal Validity): Certainly organizational histories, administrator characteristics, and specifics of the school-wide initiative could be responsible for some of the trends we observed in our data. But we note that the distribution of potential know-how flow from provider subgroups is related to *change* in implementation of the school-wide initiative. Therefore any static aspect of a school that was manifest at time 1 was controlled for (see Steiner et al., 2010, for the value of controlling for prior measurements in approximating the results from randomized experiments).

Nonetheless, one might raise the concern that unmeasured factors could be responsible for change in implementation. While we cannot control for unobserved factors in our model, we report what the characteristics of the unobserved factors would have to be to invalidate our inference of an effect of the entropy of potential know-how flow on change in implementation of the school-wide initiative. In particular, drawing on Frank (2000) an omitted confounding variable would have to be correlated at .6 or higher both with potential provider entropy and with change in implementation of the initiative to invalidate our inference of an effect of potential provider entropy on mean change in implementation of the school-wide initiative (assuming the two correlations are equal to maximize the impact of the confounder).

Correlations of .6 are considered large by social science standards (Cohen and Cohen, 1983), especially to be associated with *change* in implementation. As a basis of comparison, the years of duration of the school-wide initiative was our strongest covariate, correlated at -.16 with potential provider entropy and at -.18 with change in implementation. [7] Correspondingly, the correlations associated with an unobserved confounder would have to be more than three times greater than the correlations associated with the duration of the initiative to invalidate our inference. Although our inference can still be challenged, we encourage researchers and policy makers to discuss challenges to our inferences in the quantitative terms of the impact of a confounder necessary to invalidate the inference.

Concerns about Omitted Variables (Internal Validity): There may also be concerns about the external validity of the inference that potential provider entropy affects changes in implementation because of our relatively small, purposeful, sample. In response, we quantify how much of the estimated effect of potential provider entropy must be due to sampling bias to invalidate our inference (Frank and Min, 2007). In particular, to invalidate our inference, one would have to replace one third (about 7) of our schools with other schools in which there was no effect (Frank, Maroulis, Duong and Kelcey, 2013). [8] Note that our sample differed from state averages on % free and reduced lunch and % white by only 12%. Thus we would retain our inference even if we replaced a few of the schools to make the sample demographics equivalent to those for the state (and if there were no effect in the replacement schools). Furthermore, while our inference may be due to sampling bias, we know of no nationally representative data set that contains full sociometric and longitudinal required to estimate our models.

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[7] The negative signs offset each other – see Frank (2000).

[8] This is about at the median of robustness for articles recently published in *Edication, Evaluation, and Policy Analysis* (Frank et al., 2013).

DISCUSSION

What is a “good” network for an organization? We have examined the relationship between the distribution of know-how that bridges between subgroups and systemic change. Our key finding is that the more restricted the knowledge flows *from* potential provider subgroups, the greater the organizational change (hypothesis 2). There was no evidence to infer a relationship between the distribution of know-how *to* potential receivers and systemic change (hypothesis 1). A good network is one in which, given overall levels of knowledge flow, the subgroup sources from which knowledge flows are restricted.

Of course, receiving resources is important and systems work better when they have greater amounts of just about any form of resource relevant to implementing change. But our study is about how to best distribute a fixed set of resources, namely know-how. Our findings speak to the coordination value of cultivating flows from a small number of specialized helpers rather than from disparate others. In contrast, given a fixed amount of know-how to distribute, there is no evidence that it is better to distribute evenly to all subgroups than to just a few.

We can interpret our findings in terms of the flows in Figure 2. The know-how flowed almost exclusively from subgroups B and C, contributing to important changes in practices, especially in subgroup A. But the know-how did not flow evenly throughout the school, as subgroups D and E had little access to know-how. Nonetheless the common sources of know-how allowed the teachers in subgroups A, B, and C to coordinate their practices enough to generate increases in the school-level implementation of technology.

The literature on intra-subgroup interactions suggests two interpretations of our findings relative to the conceptualizations of know-how we raised in introducing our hypotheses. First, through their interactions and own experiences, the members of a high implementing subgroup may integrate sets of practices into regimes that can be more easily implemented by others than can be discrete practices (Thomas-Hunt, Ogden, and Neale, 2003; Tsai, 2001). Second, members of high implementing subgroups may learn to make their know-how more explicit as they engage in interactions focused on a particular set of practices (Feld, 1981; Nonaka, 1994; Yasumoto, Uekawa, and Bidwell, 2001). Either by integrating practices into a coherent whole or learning to articulate their know-how, members of high implementing subgroups may add value to the stock of know-how in their organizations, contributing to their organization's overall capacity to implement innovations.

Implications for Other Organizations

Based on the preceding analysis, our findings apply most directly to organizations that share two characteristics of teaching. First, restricting the set of providers of know-how may have greater value when practice not only requires local adaptation, but is complex in the sense that practices or more valuable when integrated into regimes. This might apply, for example, for integrated management of natural resources (e.g., Sayer and Campbell, 2003) or even in apparel manufacturing in which patterns must be coordinated with fabric (Uzzi, 1996). In these situations, those who have generated coherent regimes from sets of practices, for example through frequent interactions with a small set of likeminded others, will add value to their organization's capacity to change. Second, restricting the set of providers of know-how may have greater value when workers are not easily able to articulate their knowledge (Brown and

Duguid, 1991). In these situations, those who have learned to articulate their knowledge through frequent interactions will add value to convey to their organizations.

In other contexts, the distribution of resources *to* potential recipient subgroups may be the more salient factor. These may occur when knowledge can be easily integrated into know-how. Under these conditions, there is little loss of efficiency if subgroups access disparate sources of knowledge and each subgroup integrates the components independently. For example, factory workers may be able to easily integrate information about a new machine from one source and safety gear from another – the information about patterns and materials is essentially additive, and so the workers may benefit from having multiple sources for different types of information.

More generally, our study assumes production is complex, not hierarchically controlled, and that the organization is essentially cooperative (Marschak and Radner, 1972 -- see Williamson, 1981, on the function of the firm in internalizing potentially competitive behaviors). In these cases know-how such as what flows through intra-organizational networks is relevant for production. Our theory and findings will have less relevance to organizations that are controlled through shared values (Wiener, 1988) or rules (Weber, 1922 [1947]). But even if schools did not represent other organizations, education is a large industry. In the United States there are approximately 2.6 million teachers in about 99,000 elementary schools such as those featured in our study (United States Census: Statistical Abstract of the United States: 2007; National Center for Education Statistics, 2008).

The Role of the Manager

At their broadest, our findings suggest that managers such as school principals and other leaders should consider how to distribute existing resources through networks within a given system (Spillane 2006). In particular, managers may seek to facilitate production in organizations such as schools by identifying and cultivating a few potential subgroups as providers of know-how and ensuring that those subgroups can convey their know-how to other subgroups throughout the school. This could be accomplished by allocating resources to maximize interactions with members of subgroups with the greatest know-how in a particular set of practices. For example, administrators may release members of high know-how subgroups from their routine obligations so they may engage in more interactions with members of other subgroups.

In suggesting a role for managers, we do not conceive of the organization as a rational system controlled by managers (e.g., Weber 1922 [1947]). Instead, we conceive of managers establishing contexts for know-how sharing that contribute to productivity (e.g., Nahapiet and Ghoshal, 1998; Williamson, 1981). The importance of the manager is emphasized by recent findings in neuroscience and cognition indicating organizational members may seek out and provide help from organizationally distant actors as they internalize norms (Srivastava and Banaji 2011). And these norms, as well as opportunities facilitating collaboration, can be shaped by managers.

While cultivating know-how flow from a few potential providers may seem straightforward, it would not be without challenges (Nahapiet and Ghoshal, 1998). In the case of schools, facilitating know-how flow from a small portion of subgroups may elevate the status of some teachers at the expense of others. While this may be the goal of an actor following Burt’s (1992) strategy for gaining competitive advantage by engaging in bridging ties (see also Blau, 1967; Flynn et al., 2006), it goes against a strong egalitarian norm within the culture of schools (Glidewell, Tucker, Todt, and Cox, 1983; Little, 1990; Tellez, 1992). Indeed, status is not always easily conferred by other organizational members (Flynn and Lake, 2008).

In the particular case of schools, formal elevation of some teachers to “expert” status by removing them from some regular classroom instruction may make them less aware of others’ contexts and increase their social distance from others (Anagnostopoulos et al., 2010). This could dilute their know-how. Implied, it is not a simple matter of identifying know-how in an organization and making those with know-how accessible to a wide range of others. Formal and informal leaders must be thoughtful about cultivating know-how in a small proportion of high implementing subgroups and then facilitating access to that know-how without losing the benefits of shared contexts. For example, school principals can emphasize that different teachers will be designated and drawn on in different areas, thus evening out the status associated with, and distribution of, know-how over the long term.

This still leaves open the question as to why a teacher would help a member of another subgroup. Perhaps because she believes the other’s performance will affect her own (Frank, Zhao and Borman, 2004). For example, a third grade teacher seeking high performing students might help a second grade teacher whose students she will inherit in the next near (Frank, Kim and Belman, 2010). Alternatively, teachers who identify strongly with the collective of their school might allocate their help evenly throughout the school. In this sense, identity with the collective establishes a quasi-tie that spans across subgroup boundaries (Frank, 2009).

Limitations

We consider two key limitations in our relatively novel analysis of longitudinal network data in 21 separate organizations. The first is rooted in our measurement of the help one teacher provides another. We need to know in more qualitative terms about the nature and content of know-how flow through helping behavior together with its ultimate effects on practice. Helping behavior is a complex phenomenon in social-psychological and organizational terms (Hansen, 1999). For example, linking know-how flow to changes in behavior depends on the one who originally possesses tacit knowledge to articulate the knowledge, and then on the one who is exposed to new knowledge to internalize it and change behavior (Schwartz et al., 2005). The more we know about the actual content of the interactions between organizational members the more we will know about how those interactions affect behavior (cf. Coburn and Russell, 2008; Coburn and Woulfin, 2012; Nahapiet and Ghoshal, 1998).

Second, we have taken the social structure of an organization as given. But informal and formal social structures are shaped as organizations learn and respond to external forces (e.g., Levitt and March 1988). Thus it would be valuable to know how relationships such as close collegial ties or particular interactions such as those related to the flow of know-how change. We suggest that the exploration of such interactions should begin with theories of how individuals choose with whom to interact and share resources (for examples Frank, Kim and Belman, 2010; Frank, 2009). From there one can build to the emergence of organizational level structure through induction or simulation techniques such as agent based modeling (e.g., Wilensky and Resnick, 1999).

Conclusion

What is a “good” network for an organization? Our answer is that it depends on how resources for specific goals flow through the network. Therefore there is no single “good” network. The value of the network will depend on its capacity to channel resources to support a particular practice. Here we examined the distribution of resources by locating them relative to network subgroups and then related potential flows to systemic change. This has generated the finding that the more restricted are the sources of flows from subgroups the greater will be systemic change. We have no doubt that other novel hypotheses and findings will emerge as researchers attend to the relationship between potential resource flows and organizational behavior.

ON LINE TEHCNICAL APPENDIX A

Motivation for the Measure of Entropy (adapted from Shannon, 1948 and Cover and Thomas, 1991)

In this technical appendix we adapt Shannon’s measures of entropy to characterize the uncertainty of potential know-how flow *to* and *from* subgroups. We then standardize the measures for comparison across schools.

Formally, let n represent the number of possible links along which information could flow. The larger the number of links, the greater the uncertainty. If the links have equal probability of occurring, then uncertainty is proportional to 1/(probability of any given link). To create an additive measure of uncertainty across multiple independent links, for each link take the natural log of 1/probability, and then sum. Thus the combined uncertainty of links from A to B and from B to C is $Ln[1/p(A,B)] + Ln[1/p(B,C)] = Ln[p(A,B)^{-1}] + Ln[p(B,C)^{-1}] = -Ln[p(A,B)] - Ln[p(B,C)]$. Then, because each event is not equally likely to occur, weight the events by their probability. This generates an expected value, or average: $-p(A,B)Ln[p(A,B)] - p(B,C)Ln[p(B,C)]$. Summing across all pairs, entropy= $-\sum_A^n \sum_B^n p(A,B)Ln[p(A,B)] = \sum_A^n \sum_B^n p^*(A,B)$, as in the main text.

Deconstructing Resource Flow to Potential Receivers and from Potential Providers

The flow of resources across the network can be differentiated into a component based on the aggregated flows *to* each potential receiver and *from* each potential provider. Formally, let

$$E_{potential\ receivers} = -\sum_{A,B} p(A,B)Ln\sum_B p(A,B), \text{ and (A1)}$$

$$E_{potential\ providers} = -\sum_{A,B} p(A,B) Ln \sum_{A} p(A,B). \text{ (A2)}$$

Note $E_{potential\ receivers}$ and $E_{potential\ providers}$ are differentiated by the terms over which they are summed, B and A respectively, where subgroup A contains members who receive information from potential providers who are members of subgroup B.

Standardizing Measures of Entropy for Comparison Across Systems

To standardize the measures of entropy across systems we leverage the fact that the maxima of the entropy measures is well defined and interpretable. For example, the Max($E_{potential\ receivers}$) is the log of the number of potential receivers in that system. Defining f_{AB} to take a value of 1 if subgroup A receives resources from B, 0 otherwise then

$$Max(E_{potential\ receivers}) = Ln\left[\sum_{B}\sum_{A} f_{AB}\right]. \text{ (A3)}$$

We then use Max($E_{potential\ receivers}$) to normalize $E_{potential\ receivers}$ for comparison across systems: Z($E_{potential\ receivers}$)= $E_{potential\ receivers}$ -Max($E_{potential\ receivers}$). The term Z($E_{potential\ receivers}$) is then a function of the know-how flow to potential receivers relative to the potential evenness of know-how flow to potential receivers. The more negative the value, the more certainty about the location of know-how flow to a potential receiver relative to the baseline maximum. We use this standardized measure in our regression analyses. Similarly, we standardize the measures of potential providers**.**

ON-LINE APPENDIX B

Multilevel Estimation of Main Models

The estimates in Table 4 can be obtained alternatively by a multilevel model for teacher *i* in school *j*:

Level 1 (teacher level):

$$\text{change in implementation}_{ij} = \beta_{0j} + e_{ij};$$

Level 2 (school level):

$$\beta_{0j} = \gamma_{00} + \gamma_{01}\text{potential receiver entropy} + \gamma_{02}\text{potential provider entropy} + u_{0j}.$$

Where the u_{0j} are assumed N(0,τ). A positive value of γ_{01} indicates that the greater the entropy of the flow of resources to potential recipients, the greater the change in implementation (hypothesis 1). A negative value of γ_{02} indicates that the less the entropy of the flow of resources from potential providers, the greater the change in implementation (hypothesis 2). Estimates from the multilevel model are given below. The parameter estimates for potential provider entropy were well within 10% of those reported in the main text, and none of our inferences change from the model we report in the main text. Therefore we present the single level regressions in the main text for their interpretability in terms of the model coefficients and the graphical and sensitivity analyses.

Alternative to Table 4

Multilevel Regression of School Level Change in Implementation of the School-wide Initiative on Measures of Entropy

Independent Variable	Model 1	Model 2 (Potential Confounding)
Intercept	-.69	-.53
	(.43)	(.49)
Potential receiver entropy	0.31	.21
	(0.93)	(.94)
Potential provider entropy	-3.11**	-3.12**
	(1.09)	(1.09)
Duration of the school-wide initiative		-.05
		(.08)
Overall R^2	15%	.15%

* $p \leq .05$; ** $p \leq .01$. n=21 schools.

6% of the variance is at the school level in an unconditional model.

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Table 1

Characteristics of Schools in the Sample

School	Enrollment	Percent Free/Reduced Price Lunch	Native American	Asian	African American	Hispanic	White	Multiple Races
A	668	0.15%	0.3%	8%	2%	4%	84%	2%
B	730	85.89%	0.0%	8%	10%	82%	0%	0%
C	526	24.71%	0.0%	10%	3%	42%	40%	6%
D	354	20.90%	0.9%	9%	3%	28%	52%	7%
E	501	1.80%	0.3%	8%	1%	13%	58%	21%
F	301	Missing	0.3%	8%	0%	7%	71%	14%
G	527	18.79%	1.0%	13%	3%	68%	15%	0%
H	1036	36.49%	0.9%	13%	10%	29%	43%	5%
I	274	45.99%	0.0%	9%	23%	24%	32%	11%
J	315	70.16%	0.0%	6%	66%	26%	1%	2%
K	321	8.41%	0.6%	17%	4%	19%	55%	6%
L	480	22.29%	0.4%	8%	1%	17%	65%	9%
M	455	65.89%	0.8%	19%	3%	64%	10%	3%
N	633	66.82%	0.1%	3%	1%	55%	37%	4%
O	611	52.22%	0.0%	3%	0%	90%	6%	1%
P	434	5.30%	0.7%	31%	2%	8%	58%	0%
Q	784	8.29%	0.2%	11%	0%	10%	70%	8%
R	771	100%	0.0%	19%	9%	67%	3%	2%
S	526	49.81%	0.4%	2%	1%	69%	24%	4%
T	1088	9.10%	0.4%	18%	17%	57%	7%	1%
U	473	74.21%	0.0%	16%	2%	76%	4%	2%
V	627	69.17%	0.0%	3%	7%	86%	2%	2%
W	476	4.62%	0.8%	13%	1%	13%	52%	20%
X				Missing				
SAMPLE AVERAGE	*561*	*38.23%*	*0.4%*	*11.1%*	*7.4%*	*41.4%*	*34.2%*	*5.6%*
STATE AVERAGE	**676**	**50.6%**	**0.7%**	**8.6%**	**6.5%**	**52.0%**	**26.1%**	**2.1%**

Table 2

Characteristics of Teachers in the Sample

	N	%
Gender		
Male	73	17.2%
Female	352	82.8%
Race/Ethnicity		
White	338	79.5%
African American	11	2.6%
Hispanic/Latino	43	10.1%
Asian	18	4.2%
Other/Unknown	15	3.5%
Certification Status		
Provisional	57	13.4%
Emergency	5	1.2%
Clear	341	80.2%
National Board	9	2.1%
Missing	13	3.1%

Table 2 Continued

*Teaching Assignment**		
PreK	3	0.7%
K	31	7.1%
1	61	14.0%
2	48	11.0%
3	57	13.1%
4	28	6.4%
5	54	12.4%
6	37	8.5%
7	10	2.3%
8	40	9.2%
9	2	0.5%
10	12	2.8%
11	6	1.4%
12	32	7.4%

*****Some teachers listed multiple assignments.

Table 3

Correlations among Change in Level of Implementation of the School-wide Initiative and Measures of Entropy

	Change in implementation of the school-wide initiative	Potential receiver entropy	Potential provider entropy
Potential receiver entropy	-.059		
Potential provider entropy	-.654**	.236	
Mean	.056	-.329	-.244
Std	.759	.197	.160

* $p \leq .05$; ** $p \leq .01$; *** $p \leq .01$.

Table 4

Regression of School Level Change in Implementation of the School-wide Initiative on Measures of Entropy

Independent Variable	Model 1	Model 2 (Potential Confounding)
Intercept	-.60	-.44
	(.30)	(.35)
Potential receiver entropy	0.39	.28
	(0.70)	(.71)
Potential provider entropy	-3.22**	-3.18**
	(.86)	(.87)
Duration of the school-wide initiative		-.05
		(.06)
R^2	.44	.46
(adjusted R^2)	.38	.37

* $p \leq .05$; ** $p \leq .01$. n=21 schools.

Figure Captions

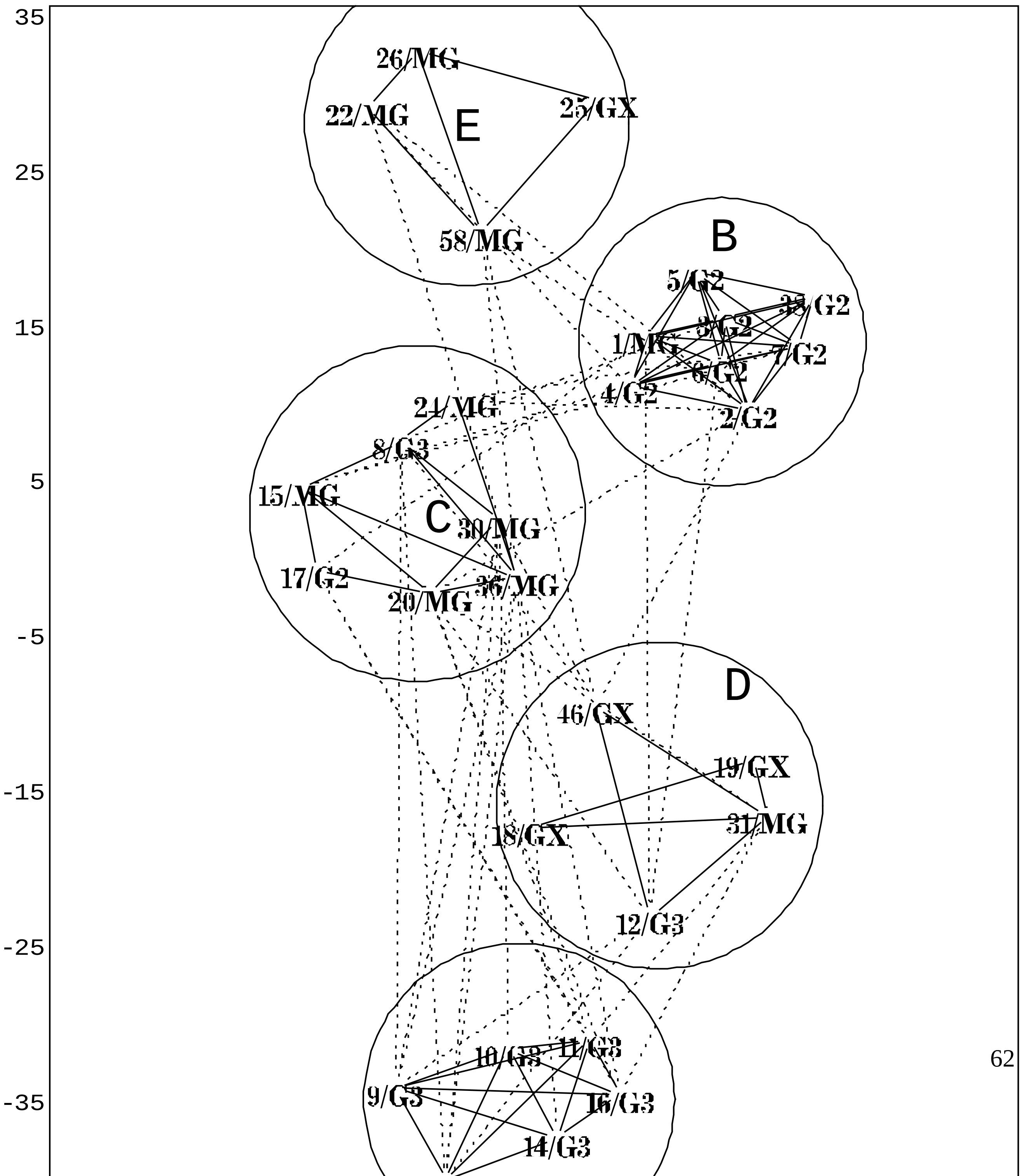
Figure 1: Crystallized Sociogram of Close Colleagues in Westville School

Figure 2. Talk about Technology Within and Between Subgroups at Westville including Changes in Levels of Technology Use

Figure 3. Entropy: The Sum of Two Transformed Resource Flow Probabilities

Figure 4. Linear Trend between Potential Provider Entropy and Change in Implementation of the School-wide Initiative

Figure 1: Crystalized Sociogram of Close Colleagues in Westville School



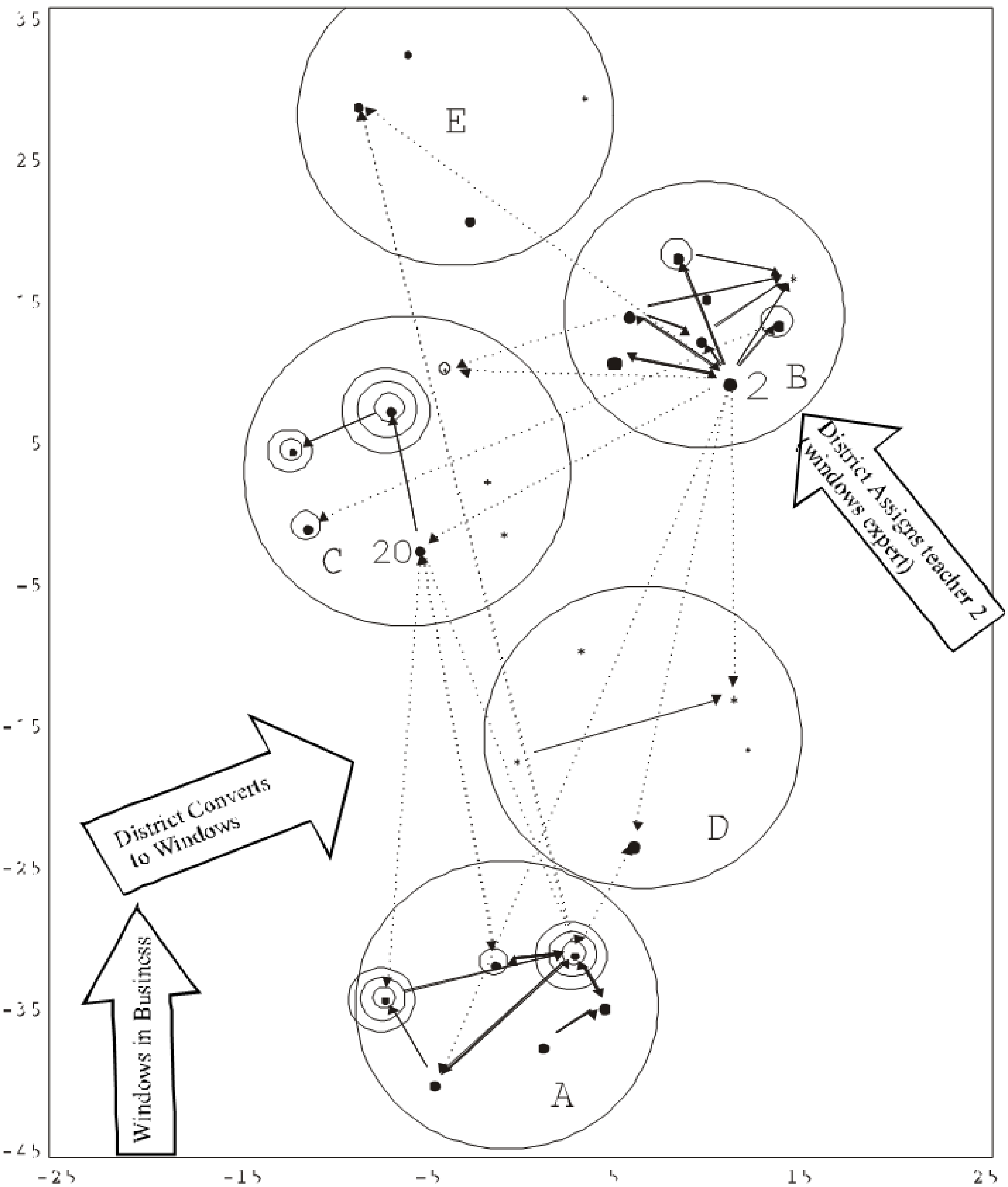


Figure 2. Talk about Technology Within and Between Subgroups at Westville including Changes in Levels of Technology Use

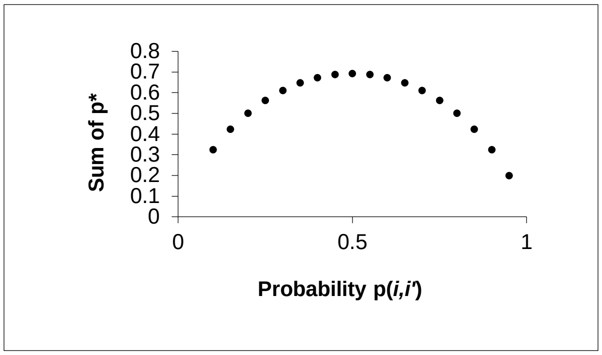


Figure 3

Entropy: The Sum of Two Transformed Resource Flow Probabilities

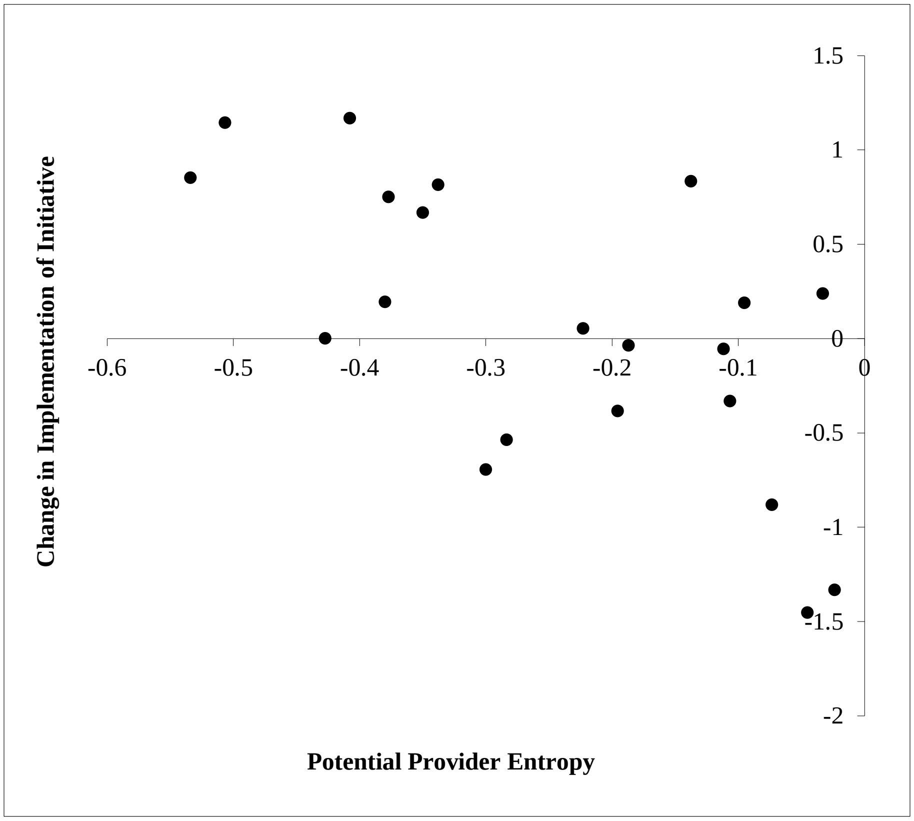


Figure 4

Linear Trend between Potential Provider Entropy and Change in Implementation of the School-wide Initiative