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Reviewed work(s):
Source: *American Journal of Education*, Vol. 119, No. 1 (November 2012), pp. 103-136
Published by: The University of Chicago Press
Stable URL: http://www.jstor.org/stable/10.1086/667756
Accessed: 18/10/2012 22:52

Using Social Network Analysis to Study How Collegial Interactions Can Augment Teacher Learning from External Professional Development

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This article presents an analysis showing how collegial interactions can augment the mechanism of teachers' learning from professional development. The analysis relies on social network data and self-reports of writing instructional practices from teachers in 20 different schools that were part of a longitudinal study of the National Writing Project's partnership activities. The results indicate that both organized professional development and interactions with colleagues who gained instructional expertise from participating in prior professional development were associated with the extent to which teachers changed their writing processes instruction. Furthermore, the effects of professional development varied by teachers' baseline practices. The study illustrates the potential for using data on teachers' social networks to investigate indirect effects of professional development and the variation in professional development effects associated with different initial levels of expertise.

A consensus—backed by a growing body of evidence from well-designed studies—has emerged about features of professional development that can change teacher knowledge and practice. Specifically, research has found that professional development can enhance teacher knowledge and improve instructional

Electronically published September 18, 2012

American Journal of Education 119 (November 2012)

0195-6744/2012/11901-0005$10.00

practice when it is sustained over time, focuses on enhancing the knowledge and skill needed to teach in specific content areas, employs active learning strategies in which teachers practice new pedagogical skills and receive feedback from others, and creates opportunities for collaborative learning from peers (Desimone et al. 2002). Professional development with these characteristics can also support better curriculum implementation (Penuel et al. 2007) and enhanced student learning (Penuel et al. 2011; Saxe et al. 2001).

A separate body of research has focused on teacher learning from collegial interactions. This research has explored the conditions under which teachers within schools form professional learning communities that enable teachers to reflect on and improve their practice (McLaughlin and Talbert 2006; Woolworth et al. 2001). Case analyses have illuminated the critical conditions for forming such communities, including a shared goal for improvement (Scribner et al. 2007), a commitment to opening up one's practice to others (Little 2002), and a strong alignment between the formal or designed social organization of schools and the actual pattern of collegial ties (Bidwell and Yasumoto 1997). These conditions, in turn, enable teachers to reconstruct their practice through repeated interactions around artifacts and representations of teaching practice and student thinking (Kazemi and Franke 2004; Little 2003), opportunities to observe one another engaged in the act of teaching (Lewis et al. 2006), and routines for scaffolding interactions about teaching (Horn and Little 2010).

In recent years, researchers have used quantitative techniques to analyze the effects of professional development and collegial interactions on teacher practice as indicators of what teachers can learn from professional development. Quantitative studies of professional development have yielded useful insights into a number of correlates of effective professional development. One such correlate

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is coparticipation in professional development with colleagues, as reported by teachers (e.g., Garet et al. 2001). Although this approach has shown that participating with peers is a correlate of effective professional development, it offers little insight into how collegial interactions might matter for teacher learning. Social network analysis offers one approach to studying such processes, and a number of researchers have begun to use social network data to model the conditions under which collegial interactions can influence teachers' instructional practices (e.g., Penuel et al. 2011). In particular, models fit to social network data can estimate the social influence of particular colleagues on one another's practice; when coupled with data on these colleagues' expertise, researchers can gain insight into the effects of particular interactions on practice.

In this study, we use some techniques of social network analysis to model how teachers' informal collegial interactions can augment the effects of organized professional development activities. The context for the study is a national evaluation of partnership activities within the National Writing Project (NWP), an infrastructure for instructional improvement focused on writing instruction. In the partnerships studied, leaders in Local Writing Project (LWP) sites and schools codesigned and led professional development that had a common content focus (writing), but they employed a wide range of strategies for reaching and supporting teachers that varied in their duration. We used this variation in exposure to professional development within schools to study how professional development could be augmented by collegial interactions, as well as how this mechanism worked differently for different groups of teachers, by drawing upon social network data and self-report data on instructional practice collected from annual surveys over the course of the first 3 years of the study.

Theoretical Background

Teacher Learning in Organized Professional Development

There is a growing body of evidence to support what Ball and Cohen (1999) call a "practice-focused" theory of teacher learning and development. This theory situates the learning needs of teachers within the kinds of teaching practices that policy makers seek to promote. It posits strategies for making practice the focus of organized professional development activities and the object of ongoing investigations, so that learning becomes fully embedded within teachers' everyday work. In short, it seeks to maximize teachers' learning about, in, and through reflection on practice.

One practice-focused strategy of organized professional development for which there is strong evidence is to provide teachers with a sustained focus on a particular content area. In their study of mathematics reform in California in the late 1990s,

Cohen and Hill (2001) found that teachers who were able to reconstruct their practice to align with the principles of new professional standards for mathematics teaching were those teachers who had participated in content-focused professional development on how to implement so-called replacement units that reflected the standards. By contrast, teachers who participated in professional development focused on instructional strategies not linked to specific content or who had limited exposure to professional development changed their practice very little. A number of subsequent studies, including nationally representative surveys of teachers and experimental evaluations of professional development, have found evidence of a link between content-focused professional development of an extended duration and changes to teachers' practice (e.g., Desimone et al. 2002; Penuel and Gallagher 2009).

A sustained focus on the content of target practices is critical because teachers interpret new reforms through both their initial teacher preparation and prior waves of reform to which they have been exposed (Coburn 2004; Spillane and Zeuli 1999). Often there are gaps between teachers' current practices and target practices of reforms (Blumenfeld et al. 2000; Cohen and Hill 2001). If that gap is too large, teachers are likely to fall back on older practices or assimilate new frameworks into how they talk about teaching without making significant changes to what they do in the classroom (Spillane and Zeuli 1999). A sustained focus on target practices in a content area that draws attention to differences and similarities between current and target practices may help to increase the chance that teachers will make changes to practices rather than assimilate frameworks into existing practices (Coburn 2004).

Beyond focusing on teacher practices, professional development that employs "active learning" strategies can support teachers in making changes to their practice. Like other learners, teachers learn best when they have the opportunity to construct knowledge using new tools for thinking and to reflect on and revise their ideas (Darling-Hammond et al. 2005). Strategies that have proven successful in providing such opportunities include giving teachers a chance to try out new practices outside the crucible of the classroom, such as in extended workshops and retreats (Lieberman and Wood 2001, 2003), to experiment with new approaches to teaching familiar content and receive task-focused feedback from peers and coaches (Coe 1998; Vaughn and Coleman 2004), and to develop an understanding of students' problematic ideas with respect to specific subject matter by looking at artifacts of student thinking (Carpenter et al. 1989; Cohen and Hill 2001). Research provides evidence that the more of these strategies that professional development activities employ, the greater the observed change to teachers' practice (Garet et al. 2001; Penuel et al. 2007).

Some organizational conditions in schools promote teacher learning in ways that are distinct from externally delivered professional development activities. For example, many schools seek to cultivate school-based professional learning communities (McLaughlin and Talbert 2006; Woolworth et al. 2001). Leaders and faculty members in such schools seek to establish norms that break down the historical isolation of teachers from one another and of individualism and privacy that are well documented in the sociology of teaching literature (Hargreaves 1993; Ingersoll 2003; Lortie 1975). These school faculties seek to instantiate Ball and Cohen's (1999) theory of "practice-focused" professional education within workplace practices so as to enable teachers—through their collegial interactions about instruction with others—to reconstruct their practices to align with goals for school-wide reform.

Under certain conditions, a number of these efforts can be successful, as case study researchers have documented. One such condition is that leaders set a clear and focused purpose for teachers with respect to instructional improvements. When particular teams of teachers receive or co-construct a charter for their work with leaders, their work together to improve practice produces a common sense of purpose to use as a benchmark for progress (Kaufman and Stein 2010; Scribner et al. 2007). Another condition is that teachers must be willing to open their practice to scrutiny by colleagues (Little 2002). This involves representing their practice to others, so that the ordinarily "small horizon" of practice in view of colleagues becomes bigger and thus open to personal and collective reflection and critique (Little 2003). It also involves a willingness to take an inquiry stance toward one's own teaching and to engage productively but critically with difference and conflict among faculty members with respect to views about teaching (Achinstein 2002; Cochran-Smith and Lytle 1999; Woolworth et al. 2001). A third important organizational condition for professional community is cohesion among faculty. Interactions among cohesive faculty, in which there is a high level of relational trust and where there are strong, positive collegial ties that link teachers across the school can communicate the knowledge and norms necessary to support teachers to change practices (Bryk and Schneider 2002; Penuel et al. 2009).

These organizational conditions both enable and are cultivated through particular social practices that support teacher learning in their schools (Bryk et al. 2010). Of central importance are routines and protocols that scaffold deep conversations among teachers about their practices (Horn and Little 2010; Kazemi and Franke 2004; Little 2003). First, protocols for looking at student work together or examining practice can provide a safe context for opening up and representing one's practice to others and thus facilitate teachers' willingness

to experiment with new practices (Curry et al. 2003; Little and Curry 2008). Second, the analysis of common artifacts, anchored to lessons or samples of student work, can also help teachers come to appreciate multiple approaches to teaching content and the plausibility of drawing different inferences about what students know and can do (Ryken 2009). Conversations anchored in practice can help teachers problematize their own practice and appreciate the need for reexamining their own knowledge and the frames of reference they bring to teaching (Herbel-Eisenman and Phillips 2008; Smylie 1996).

Using Social Network Analysis to Model Teacher Learning from Professional Development and Collegial Interaction

Few researchers have sought to develop theoretical accounts of or test models that focus on how teacher learning from organized professional development and collegial interaction relate to one another. Addressing this gap is important, because both forms of teacher learning have limitations. In practice, external professional development rarely proves sufficient for making significant changes to individual teachers' practice or to the culture of teaching in schools (Fullan 2007; Garet et al. 2011). One reason is that teachers have limited access to high-quality professional development (Darling-Hammond et al. 2009). The costs of sustained, content-focused professional development are high, and continuous changes to teachers' assignments can render content-focused professional development received as part of a previous assignment relatively useless for teachers in their new assignment (Shear and Penuel 2010). Furthermore, even when teachers do have access to high-quality professional development, organizational conditions in schools and districts can limit teachers' opportunities to experiment with new practices in their classrooms or engage in deep conversations with colleagues about problems they face in implementing new practices (Bryk et al. 2010; Coburn and Russell 2008; Gallucci 2008; Stein and Coburn 2008).

Some research suggests that interactions among colleagues can sustain the effects of professional development, either when they come to their intended conclusion or because funding or new policies limit teachers' access to activities. For example, a follow-up study of the successful Cognitively Guided Instruction professional program for elementary mathematics teachers found that in schools where teachers continued to talk together about student thinking in mathematics, as part of teacher teams in their schools, they were able to sustain improvements to their practices (Franke et al. 2001). In a different context, in which policy shifts reduced the availability of professional development available to teachers, some schools were able to sustain ongoing teacher learning opportunities when there were high numbers of content-focused teachers in a school and when

teachers share a common vision for instructional practice (Kaufman and Stein 2010). These studies, however, did not examine how professional learning communities might shape the effects of ongoing formal professional development.

Our own conjecture, derived in part from our own past research, is that frequent collegial interactions focused on instructional matters related to the content of professional development can augment the effects of that professional development. In contrast to past studies that have focused either on formal professional development or learning in teacher professional communities, the studies from which we derive this conjecture combine data on teachers' social networks with data on their exposure to professional development. We then model changes to teachers' instructional practices as a function of teachers' exposure to colleagues' expertise through social interaction and their participation in professional development.

The type of social network model we fit to our data is particularly well suited for our purposes. Social influence models analyze the attributes of people as a function of relations in a social network (Frank 1998; Friedkin and Johnsen 1990; Marsden and Friedkin 1994). Such models presume that the attributes measured at the end of a particular time period (outputs) are a function of individual and group characteristics at the beginning of that period (inputs) plus the social interactions that happen in between (Friedkin and Johnsen 1990). Social influence operates through many different kinds of mechanisms, but one of the most important ones, and the one that is the focus of our study, is information seeking (Anderson 1971; Burt 1992; Granovetter 1973). People can exert social influence over others when they have information or expertise that another person seeks; the exchange of this information often results in the seeker aligning his or her attitudes with the provider of help or acquiring knowledge that allows the seeker to do something the provider can already do but that the seeker needs to learn (Brown and Duguid 1991; Tyre and von Hippel 1997).

An example of a social influence model in education is presented in Frank and colleagues' (2004) analysis of the diffusion of technology use in six schools. In that analysis, researchers modeled technology integration as a function of teachers' access to expertise through collegial interaction and social pressure. The researchers' models considered both the capability of collegial providers of help regarding integration (as indicated by the number of people who nominated them as helpful) and their expertise (as indicated by self-reports of technology integration in their helpers' classrooms).

Social influence models provide insights that are distinct from other kinds of quantitative analyses of the context of teaching and from qualitative studies of collegial interactions and their effects on teacher learning. Many quantitative studies of the context of teaching focus on survey scales that ask teachers to report on the school as a whole (e.g., Lee and Smith 1996). Such approaches do not consider the ways that such perceptions might be a function of social

selection, social influence, or both; furthermore, they provide little insight into the social structure of interactions through which social influence operates (Maroulis and Gomez 2008). Qualitative studies often provide rich detail on social interactions and can trace well the conditions under which such interactions produce significant changes to teachers' practices in and related to the classroom (Horn 2010). At the same time, such studies necessarily focus on subgroups or teams of teachers, because data collection requires that intensive effort be focused on a few participants. Collecting and analyzing social network data sacrifices the depth of such analysis for an increase in breadth and comprehensiveness: models fit to the data enable researchers to draw inferences about how the social structure and composition of school communities as a whole influence teachers' attitudes and instructional practices.

It is a relatively recent development within studies of teacher networks to consider simultaneously the effects of formal professional development and collegial interactions. Frank et al. (2011) drew from survey data of a representative sample of teachers in a single state and focused on their integration of computer technology into classroom instruction. The survey included questions about teachers' exposure to professional development, their collegial interactions, and instructional practices. The researchers found that for teachers with limited prior use of technology, formal professional development was the most effective strategy for developing that practice, but for those with the most prior exposure, collegial interaction was most effective.

Though cross-sectional in design, the findings from the Frank and colleagues (2011) study suggest the plausibility of a developmental theory of the relation of formal professional development to collegial interaction. We propose that when teachers have limited experience in implementing a target practice—whether it be reform mathematics, inquiry teaching in science, technology integration, or (as in the case of the current study) a process approach to writing instruction—organized professional development will be critical for their learning. They need sustained professional development to change their practice, because the gap between current and target practices is so great; without the intensity of messages related to the content of professional development, teachers are likely to assimilate new ideas into their existing frameworks for teaching rather than change them. At the same time, for teachers who may already be expert in a target practice, collegial interaction may benefit them especially, because it helps them integrate and contextualize the abstract knowledge of teaching gained outside the organizational context of their school. These teachers' needs differ from other teachers' needs in that their primary learning goals are to develop more nuanced, differentiated approaches to teaching that are facilitated by interacting with colleagues about their practices.

The Current Study

The National Writing Project has provided for more than 35 years an infrastructure for instructional improvement focused on writing instruction, organized as a network of 200 Local Writing Project sites that are housed in universities. LWP sites offer invitational professional development institutes and opportunities for follow-up focused on teacher leadership development, lead programs for young writers, and a range of in-service programs for teachers, schools, and school districts, including codesigned professional development partnerships with schools. LWP sites have substantial discretion in how they and their partner schools plan partnership professional development as well as in the content, format, and duration of the professional development they provide; however, all NWP professional development uses teacher collaboration as a central mechanism through which teachers can continually improve their practice.

The current study described the extent of changes in teachers' instructional practices in a sample of partnership schools. It then examined the relationship between NWP professional development and changes in instructional practices to see if these relationship were augmented by collegial interactions around writing instruction in partnership schools. We asked the following questions:

1. Is participation in sustained, content-focused professional development in writing related to changes in the level of implementation of practices focused on teaching writing processes?
2. Is interaction with colleagues who participated in sustained professional development related to changes in teachers' practices beyond the net effect of direct participation in professional development?
3. Are the relationships between professional development, interaction with colleagues, and instructional practices described above different for teachers with different baseline levels of implementation of practices?

We ask these questions in the context of a national experimental evaluation of partnership activities of the National Writing Project. Although its invitational institutes have been the focus of much research, study, and self-reflection (e.g., Gray 2000; Lieberman and Wood 2004, 2003; McDonald et al. 2004), prior to the 5-year evaluation study currently under way, there had been little systematic investigation of partnerships and their affects. The national evaluation study is employing an experimental design in which schools were randomly assigned to plan and implement partnership activities with the leadership and assistance of LWPs; partnerships' affects on teaching and student writing are the main foci of that study (Gallagher et al. 2009).

The possibility for this study and impetus for it emerged from observed patterns of variation among the partnerships that formed within the treatment

group of schools in the evaluation. While the overall NWP theory of action emphasizes that there is no single right way to teach writing, a process approach to writing instruction is integrated into some sites' professional development. Further, although partnership professional development had a common focus on writing instructions, partnerships varied in the specific processes targeted in professional development. Some gave more emphasis, for example, on planning and prewriting skills, others on drafting, revising, and editing text. Beyond writing processes, partnerships focused on other topics as well; in fact, the most common area of focus was writing to learn subject matter content (see McCutcheon et al. [2008] for an overview of writing to learn strategies). As a consequence, teachers' level of exposure to writing processes and focused professional development varied across and within schools. Similarly, partnerships varied to the extent to which promoting collegial interaction was an intentional strategy for supporting teacher learning outside the context of formal professional development. In some partnerships, building professional learning communities was a focus of professional development, and, in a few cases, it was a purposeful strategy for extending the impact of partnership activities throughout the school. Variations in the content of professional development and the explicit focus on collaboration among partnership schools led us to consider how we might understand how variability in focus and strategy might explain variability in effects on teacher practice (Gallagher et al. 2011).

The current study relied on survey measures collected over the first 3 years of the evaluation study, which included a baseline year for planning and 2 years of implementation. As elaborated below, we collected data on teachers' reports of their own participation in professional development related to writing, the colleagues who provided help to them on matters of writing, and the frequency with which they engaged in different writing processes. The analyses described in detail below focused on the partnership schools (i.e., the treatment group), and the primary outcome of interest was the frequency with which teachers engaged in instruction related to different writing processes.

Sample

In the larger study of the impact of partnership activities within the National Writing Project, researchers at SRI International randomly assigned 39 schools that served middle grades students to one of the two experimental conditions: 20 schools were assigned to the partnership (treatment) condition, and 19 schools were assigned to the delayed partnership (control) condition (for more information on the larger project's design and study sample, see Gallagher et al. [2009]).

This study uses data collected from the 20 treatment schools in the larger

TABLE 1

School Characteristics in Year 3, the 2009–10 School Year

Mean	Partnership (Treatment)
Enrollment	610.6 (329.3)
FRP (%)	51.55 (25.11)
White (%)	58.56 (28.69)
Pupil-teacher ratio	13.84 (5.69)
Full-time equivalent teachers	37.75 (21.69)
Number of English language arts teachers	13.55 (7.63)

NOTE.—FRP = free and reduced-price lunch. Standard deviations appear in parentheses.

evaluation study. These 20 schools were located in 14 Local Writing Project sites across the nation. Table 1 provides demographic information of these schools for the 2009–10 school year. The average enrollment size was 611 with a standard deviation of 329. The average percentage of students who were eligible for free and reduced-price lunch was about 52%, and the majority of students were white. The average pupil-teacher ratio was around 14 : 1. The schools had an average of 38 full-time equivalent teachers, about 14 of whom taught English language arts (ELA).

The average teacher characteristics in the 2009–10 school year are included in table 2. Teachers averaged 16 years of teaching experience with a standard deviation of 9.24. On average, they had taught in current schools for more than 11 years and taught the same assignment in the current school for about 9 years. The highest degree for 95% of the teachers was a bachelor's or master's degree, and about 5% of teachers had an education specialist degree or a professional diploma based on at least 1 year's work past the master's degree. None of the teachers had a doctorate.

Measures

This study draws on annual teacher survey data from all credentialed staff (except for principals) in these 20 schools. These data include measures on professional development, teachers' professional networks, instructional practices, school contexts, and individual background information. In what follows, we will refer data collection in spring 2008 as the year 1 baseline year of data collection; spring 2009 as year 2, the first year of implementation of experiment; and spring 2010 as year 3, the second year of implementation of experiment. We briefly summarize how the measures were constructed and which wave(s) of data were used.

TABLE 2

Teacher Characteristics in Year 3, the 2009–10 School Year

	Partnership (Treatment)
Experience (mean):	
Years teaching	15.63 (SD = 9.24)
Years teaching in the current school	11.16 (SD = 7.62)
Years teaching the same assignment in the current school	8.91 (SD = 6.89)
Highest academic degree (%):	
Bachelor's	40.57 (n = 200)
Master's	54.77 (n = 270)
Education specialist	2.84 (n = 14)
Doctorate	.00 (n = 0)
Professional credential post–bachelor's degree	1.82 (n = 9)

NOTE.—SD = standard deviation; n = number of teachers.

Dependent Variable

Engagement of students in writing processes in year 3 (2009–10 school year).—In the year 3 survey, teachers were asked to rate how often they had students engage in several writing-related activities on a six-point scale: 0 = never, 1 = fewer than 5 times, 2 = 5 times or more, 3 = monthly, 4 = weekly, and 5 = daily. The items for these practices were drawn from meta-analyses conducted by Graham and Perin (2007a, 2007b) that focused on strategies of teaching writing targeting middle and high school students. Their meta-analysis included only experimental and quasi-experimental intervention studies. The strategies identified as effective that were included in survey items included brainstorming or organizing ideas for writing text, composing text, revising text (focused on meaning and ideas); editing text (focused on grammar, usage, punctuation, spelling); meeting individually with the teacher to get oral feedback or discuss how to improve his or her writing; reviewing written feedback on their own writing given by the teacher; sharing or presenting their own writing to peers; and analyzing what makes particular texts good or poor models of writing (individually or with others). We aggregated one composite variable by averaging the ratings on these items (α = 0.96).

Focal Predictors

Direct participation in professional development in year 3 (2009–10 school year).—We used teachers' self-reported contact hours in year 3 as a proxy of the amount of professional development teachers had. On the teacher survey, researchers asked teachers to indicate how many hours of professional development related to teaching writing or assessing writing they had participated in as a recipient, including workshops, conferences, classes, writing groups, and site-based professional development activities such as study groups or work on writing with a literacy coach or mentor.

Network measure on exposure to colleagues' estimated expertise gained from year 2 professional development.—We developed this measure using a two-stage process. We first estimated the extent to which teachers had gained instructional expertise from year 2 professional development. We then derived the measure of indirect exposure to professional development as approximated by the extent to which, through professional interactions, teachers were exposed to their peers' estimated amount of gain in instructional expertise from year 2 professional development.

In constructing this measure, our purpose was to estimate how the effects of professional development were augmented by teacher interactions with colleagues who benefited from professional development. To do so, we statistically estimated the amount of expertise gained from year 2 professional development and the amount of professional development expertise available to disseminate to other teachers. We used teachers' self-reported contact hours in year 2 professional development to predict teachers' instructional practices in year 2 by controlling for year 1 instructional practices. Then we multiplied the coefficient with the teachers' self-reported year 2 professional development duration to get the estimate of level of instructional practices attributable to receiving year 2 professional development, when controlled for prior instructional practice. About 56% of the total variance of year 2 instructional practices was explained by the model, and the coefficient of professional development contact hours was about 0.009 (t-ratio $=$ 5.23, p-value $\leq$ .001).[1] For example, a teacher's year 2 professional duration was 20 hours, and therefore the contribution of professional development to this teacher's gain in expertise was then estimated to be $20 \times 0.009 = 0.18$.

To illustrate the dynamics of how expertise spread among teachers, we developed a network measure of the extent to which a teacher was exposed to colleagues' estimated professional development expertise through interactions. To measure teachers' interactions, in the year 3 teacher survey, teachers were asked to list five colleagues in the same school who had provided help with teaching writing to them during the 2009–10 school year. Teachers were also asked to rate the frequency of each of the five types of interactions on a five-

point scale as follows: 0 = not at all, 1 = once or twice this year, 2 = monthly, 3 = weekly, and 4 = daily, with such comments as (1) gave me curriculum resources (e.g., texts, lesson plans, print materials for students), (2) gave a demonstration of how to lead a writing lesson or activity, (3) provided me with feedback on my teaching that I used to improve how I teach writing, (4) gave me an idea for a new writing-related activity to use with my students, and (5) helped me adapt or improve a writing activity I used with my students. The original units of the frequency of interactions were transformed to days (0 = 0 days, 1 = 2 days, 2 =0 days, 3 = 36 days, 4 = 180 days). We then summed the frequency of interactions between two teachers across these different types of interactions. For instance, teacher Lisa nominated Bob as a help provider. Bob had given Lisa curriculum resources monthly (10), a demonstration of instruction once or twice in this year (2), and an idea of a new writing-related activity every week (36). Thus, given the pair of these two teachers, Lisa and Bob, we would calculate the frequency of their interactions as the sum of these frequencies on these tasks to be 48 (10 + 2 + 36).

The exposure to help providers' estimated expertise gained from year 2 professional development was estimated by multiplying the frequency of the interaction teacher i reported with i' by the estimated amount of expertise that teacher i' learned from year 2 professional development. For example, if Bob's estimated expertise gained from year 2 professional development was 2, and the frequency of Lisa and Bob's interaction was 48, then Lisa's exposure (via Bob) would be 48 × 2 = 96. If, besides Bob, Lisa also nominated Lucy with estimated expertise of 2 (with a frequency of interactions = 180, then 180 × 2 = 360), Tracy with estimated expertise of 0.1 (with an interaction frequency of 14, then 14 × 0.1 = 1.4), and Tom with estimated expertise of 5 (with an interaction frequency of 10), then Lisa's total exposure to expertise in her network is 10 × 5 = 50. To combine information across Lisa's network, we took the sum of exposure across all teachers that Lisa nominated between 2009 and 2010:

$$\begin{aligned}&\text{exposure to colleagues' expertise gained from year 2 professional development}_i \\ &= \sum_{i'=1, i\neq i'}^{n_i} (\text{Help}_{ii'}) \\ &\times (\text{Help providers' estimated expertise gained from year 2 professional development}_i).\end{aligned} \tag{1}$$

In equation (1), n_i is the number of teachers i (e.g., Lisa) indicated as providing help with writing instruction (e.g., $n_i = 4$), and $\text{help}_{ii'}$ represents the frequency with which teacher i (e.g., Lisa) reported receiving help from i' (e.g., Bob). In

the previous example, the exposure of Lisa to her colleagues would equal 507.4 (96 + 360 + 1.4 + 50).

Analytic Strategies

The logic of estimation is straightforward; that is, we assume that the change in the teachers' instructional practices was a function of their own participation in professional development and exposure to colleagues' estimated expertise gained from year 2 professional development (Frank and Fahrbach 1999). We used several statistical strategies to help establish confidence in drawing causal inference.

First, we controlled for teachers' prior instructional practice in year 1. Although schools were randomly assigned to the treatment condition of forming a partnership with Local Writing Project sites, teachers within treatment schools were not randomly assigned to receive treatment. A key concern in this case is selection bias—namely, that teachers with particular characteristics might be more likely to select to participate in professional development and that those characteristics might also be related to the outcome (current instructional practice). We used statistical adjustments for measured characteristics, specifically teachers' instructional practice in year 1, to reduce bias in the estimates and make the estimates as precise as possible. Our past research indicates that teachers' prior instructional practice is likely highly related to current instructional practice (Frank et al. 2011; Penuel et al. 2011). Additionally, unobserved characteristics of teachers, like teachers' interest in writing or motivation to improve instruction at baseline may also be related to both their prior and current instructional practices, as well as to their propensity to participate in professional development (Desimone et al. 2006). As a result, prior instructional practice is a promising covariate for reducing bias in the estimate of the relationship between professional development and collegial interactions on current instructional practice.

Second, we also accounted for several teachers' current background characteristics that we hypothesized could be related to teachers' instructional practices. For example, we controlled for whether the teacher taught English language arts in year 3 because ELA teachers were more likely to know how to teach writing well than teachers who taught other subject areas. Moreover, having an advanced degree, such as a master's or higher, might affect the quality of instruction teachers provided to their students. Additionally, if teachers were instructional writing coaches and/or teacher consultants, they were expected to be more involved in professional development and more likely to have higher levels of expertise in teaching writing. For each of these characteristics, we created a dummy variable assigned as one if the teacher had the characteristic

(e.g., taught ELA in year 3), otherwise, zero. Gender may be related to teachers' choice of collaborative partners and their collaborative experiences (Van Benschoten 2008), so we also included a dummy variable assigned as one if the teacher was female. Furthermore, we controlled for teachers' years of experience at the current school and their perceived pressure to improve student performance on the state writing assessment (0–7 scale).

Third, we included a dummy variable for school fixed effects to account for disparities across schools that may confound the effect of professional development on the outcome (e.g., higher capacity schools were more successful in forming effective partnership with Local Writing Project sites).[2] In sum, the estimation model is simplified as follows:

$$
\begin{aligned}
\text{Instructional practice in year } 3_i = {} & \beta_0 \\
& + \beta_1 \text{ Direct participation in professional development in year } 3_i \\
& + \beta_2 \text{ Network measure of the exposure to colleagues' estimated expertise gained from year 2 professional development}_i \\
& + \beta_3 \text{ Prior instructional practice in year } 1_i \\
& + \beta_4 \text{ Being an ELA teacher in year } 3_i \\
& + \beta_5 \text{ Being a female}_i \\
& + \beta_6 \text{ Years of working at the current school up to year } 3_i \\
& + \beta_7 \text{ Being a coach or teacher consultant in year } 3_i \\
& + \beta_8 \text{ Having a master's degree or higher in year } 3_i \\
& + \beta_9 \text{ Perceived pressure on improving student performance on state writing assessment in year } 3_i \\
& + \sum \beta_p \text{ School dummy variable}_i \\
& + e_i,
\end{aligned}
\tag{2}
$$

where $\beta_{1–9}$ is the coefficient of each predictor, which represents the direction

and strength of association between each predictor and the outcome variable; β_p represents the dummy variables for school fixed effects where teacher i worked; and e_i is assumed to be normally distributed with mean 0 and variance of σ^2. Fitting this model enabled us to estimate the direct effect of attending writing professional development in year 3 and the additional indirect effect from interacting with colleagues who participated in year 2 professional development, adjusting for measures of teachers' prior practice, teacher characteristics, and school fixed effects.

To address question 3—how the effects of professional development and collegial interaction differ for teachers with different baseline instructional practices—we separated the whole sample into three groups based on teachers' baseline frequency of engaging students in a variety of writing processes: a low frequency group (the frequency of fewer than five times in year 1, lower than one-third of the standard deviation below the mean, $n = 147$, about 34% of the sample), an intermediate frequency group (between the frequency of fewer than five times and almost monthly, between one-third of the standard deviation below the mean and two-thirds of the standard deviation above the mean, $n = 153$, about 35% of the sample), and a high frequency group (the frequency of monthly or more, higher than two-thirds of the standard deviation above the mean, $n = 131$, about 30% of the sample). We then estimated the second equation within each group. We used SAS software to estimate the models.[3]

Results

Descriptive Statistics

Below, we present descriptive statistics regarding professional development exposure, collegial interaction, and self-reported writing processes instruction, as shown in table 3. We present both statistics for the whole sample, as well as statistics disaggregated by teachers' baseline level of implementation of writing processes instruction.

Exposure to professional development and collegial interaction.—Within partnership (treatment) schools, teachers had an average of 10 hours of professional development with a standard deviation of 21 hours. The average of the amount of network exposure to colleagues' expertise gained from year 2 professional development was about 1.152 units with a standard deviation of 1.5. A "unit" of this variable is a combination of the frequency of interactions with colleagues and colleagues' estimated expertise gained from year 2 professional development.

Mean instructional practices, adjusted for prior practices.— The mean frequency of instructional practice in engaging students in writing processes in year 3 is

TABLE 3

Descriptive Statistics of Focal Measures by Low, Intermediate, and High Frequency Groups

Variable	Whole Sample ($n = 431$)	Low ($n = 147$)	Intermediate ($n = 153$)	High ($n = 131$)
Writing processes instruction in year 3	1.684	.692	1.685	2.829
	(1.343)	(.911)	(1.072)	(1.123)
Prior writing processes instruction in year 1	1.646	.194	1.569	3.411
	(1.374)	(.232)	(.572)	(.522)
Direct participation in professional development in year 3	10.271	4.168	9.540	18.167
	(20.695)	(7.538)	(21.611)	(26.658)
Network measure of the exposure to colleagues' estimated expertise gained from year 2 professional development	1.152	.632	1.162	1.739
	(1.548)	(1.230)	(1.460)	(1.759)
ELA teacher in year 3	.298	.032	.244	.677
	(.458)	(.177)	(.431)	(.470)
Female	.681	.630	.625	.807
	(.466)	(.484)	(.486)	(.396)
Years working at current school up to year 3	11.156	11.333	10.983	11.155
	(7.631)	(7.642)	(7.499)	(7.817)
Coach or teacher consultant in year 3	.074	.046	.085	.093
	(.262)	(.211)	(.280)	(.292)
Master's degree or higher in year 3	.585	.584	.528	.653
	(.493)	(.494)	(.501)	(.478)
Perceived pressure on improving student performance on state writing assessment in year 3	5.986	5.945	6.064	5.939
	(1.462)	(1.471)	(1.427)	(1.499)

NOTE.—Standard deviations are included in parentheses. ELA = English language arts.

about 1.684 (less than five times a year). This represents an estimated increase of 0.018 units from the baseline year of 1.646, which is not statistically significant ($p > .05$).

Variability in direct participation in professional development in year 3 and exposure to professional development and collegial interaction by baseline implementation of writing processes.—Teachers with the highest frequency of implementation of writing processes at the baseline year had the most opportunities to learn from both direct participation in year 3 professional development and interaction with colleagues who had participated in year 2 professional development. That is, teachers with the highest frequency of engaging students in writing processes

in year 1 subsequently experienced the most hours of professional development (18.167) in year 3 and accessed the most expertise of other colleagues through collegial interactions (1.739) compared to teachers in the lower two groups of baseline instructional practice. These differences among the three groups were statistically significant at $p < .001$.

Implementation of writing processes instruction.—On average, teachers who implemented writing processes instruction the least had engaged their students in writing processes (e.g., planning) in year 1 less than five times a year, on average, and in year 3 they increased the frequency of such practices fourfold to an average of 5 times a year per. This increase was statistically significant using a paired *t*test ($t = 6.38$, $p \leq .001$). Teachers in the intermediate frequency group made a smaller increase in the frequency of their writing processes instruction; in both year 1 and year 3, they engaged students roughly five times per year, on average, in writing processes. This change for the intermediate group was not statistically significant ($t = 1$, $p = .32$). Teachers in the high frequency group had engaged students in individual writing processes approximately monthly on average, that is, about 1.3 standard deviations above the mean of the whole sample. These teachers decreased their mean level of practices in year 3. This decrease was statistically significant ($t = -6.81$, $p < .0001$). The changes in how teachers engaged students in the writing processes from year 1 to year 3 across these three groups were significantly different from one another (using Tukey's test, $p < .05$). Thus, there was a tendency for regression to the mean, with teachers at the lowest initial levels increasing and teachers at the highest initial levels decreasing.[4]

Effects of Direct Participation in Professional Development and Augmentation through Collegial Interaction

To address the first two research questions, we used the whole sample to estimate the relationship between current writing practice and teacher characteristics, direct participation in professional development, and interactions with peers who gained expertise by participating in year 2 professional development. Table 4 indicates significant, positive correlations between individual teachers' writing processes instruction in year 3 and each of our independent variables: direct participation in professional development in year 3 ($r = 0.333$), network measure of the exposure to colleagues' estimated expertise gained from year 2 professional development ($r = 0.394$), prior instructional practice in year 1 ($r = 0.667$), being an ELA teacher in year 3 ($r = 0.561$), being a female ($r = 0.157$), and being a coach or teacher consultant in year 3 ($r = 0.101$).

Table 5 includes the results of fitting equation (2) to the data. Our model

TABLE 4

Correlation Coefficients

	Writ. Proc. Inst.[a]	Direct Participation in PD[a]	Network Measure[b]	Prior Writ. Proc. Inst.[c]	ELA Teacher[a]	Female	Yrs. Working at Current School[d]	Coach or Teacher Consultant[a]	MA or Higher[a]	Perceived Pressure[e]
Writing processes instruction in year 3	1.000									
Direct participation in professional development in year 3	.333***	1.000								
Network measure of the exposure to colleagues' estimated expertise gained from year 2 professional development	.394***	.291***	1.000							
Prior writing processes instruction in year 1	.667***	.289***	.322***	1.000						
ELA teacher in year 3	.561***	.341***	.313***	.583***	1.000					
Female	.157***	.089	.053	.176***	.209***	1.000				
Years of working at the current school up to year 3	−.007	−.046	.035	.043	−.068	.04	1.000			

Coach or teacher consultant in year 3	.101*	.095*	−.016	.086	.127**	−.07	.095*	1.000		
Master's degree or higher in year 3	.02	.108*	.084	.048	.086	−.041	.122*	.055	1.000	
Perceived pressure on improving student performance on state writing assessment in year 3	.034	.002	.052	−.047	.012	.175***	.039	.008	−.11*	1.000

NOTE.—Writ. Proc. Inst. = writing processes instruction; PD = professional development; ELA = English language arts; Yrs. = years; MA = master's degree. $N = 431$.

[a] In year 3.

[b] Measure of exposure to colleagues' estimated expertise gained from year 2 PD.

[c] In year 1.

[d] Up to year 3.

[e] Pressure on improving student performance on state writing assessment in year 3.

* $p \leq .05$.

** $p \leq .01$.

*** $p \leq .001$.

TABLE 5

Professional Development Effects on Teachers' Writing Processes Instruction in Year 3 Using the Whole Sample

Variable	Estimate	Standard Estimate
Direct participation in professional development in year 3	.007**	
	(.002)	.108
Network measure of the exposure to colleagues' estimated expertise gained from year 2 professional development	.144***	
	(.037)	.173
Prior writing processes instruction in year 1	.458***	
	(.042)	.475
ELA teacher in year 3	.552***	
	(.127)	.193
Female	−.001	
	(.103)	.000
Years of working at the current school up to year 3	−.001	
	(.006)	−.007
Being a coach or teacher consultant in year 3	.144	
	(.182)	.028
Master's degree or higher in year 3	−.102	
	(.102)	−.038
Perceived pressure on improving student performance on state writing assessment in year 3	.052	
	(.034)	.058
R^2	.55	

NOTE.—$N = 431$; ELA = English language arts. Standard errors are in parentheses. School fixed effects were estimated but not included in this table. We estimated school random effects and group mean-centered all variables listed in this table by using hierarchical linear models: teacher level (level 1) and school level (level 2) (Raudenbush 2009). In this alternative model, the coefficients of the variables included in table 4 did not change substantially, and using school random effects with hierarchical linear models would not alter any of our inferences.

* $p \leq .05$.

** $p \leq .01$.

*** $p \leq .001$.

explains 55% of the variation in teacher instructional practice in year 3. The strongest predictor of current practice is (not surprisingly) prior practice ($b = .475$, $p \leq .001$), followed by being an ELA teacher in year 3 ($b = 0.193$, $p \leq .001$). Controlling for prior practice and being an ELA teacher in year 3, we see that both direct participation in professional development ($b = .108$, $p \leq .01$) and interactions with peers who gained expertise by participating in year 2 professional development were significantly and positively related to teachers'

instructional practices in year 3 ($b = 0.173$, $p \leq .001$). By comparing standardized coefficients, the indirect effect of professional development through collegial interaction is more than one-third of the effect of prior instructional practice in year 1 and is even larger than the direct effect of participation in professional development. The effect of participation in professional development in year 3 is also significant, and is about one-quarter of the effect of prior practice. None of the other teacher background covariates was statistically significant in the model.

Effects of Professional Development and Collegial Interactions for Teachers with Different Baseline Frequencies of Engaging Students in Writing Processes

Results for the estimated model of teachers' instructional practice in year 3 across different groups are reported in table 6. The estimated effect of direct participation in year 3 professional development was statistically significant ($\beta = 0.203$, $p < .01$) for teachers in the low frequency group, as was the effect of exposure to colleague's expertise gained from year 2 professional development ($\beta = 0.316$, $p < .001$), after controlling for other covariates. When comparing the standardized coefficients, the indirect professional development effect through collegial interactions was larger than the direct effect of participation in professional development in year 3.

With regard to the intermediate-frequency group, the estimated effect of direct participation in year 3 professional development was statistically positively significant ($\beta = 0.013$, $p < .01$), but the estimated effect of exposure to peers' expertise was not ($\beta = 0.104$, $p > .10$). By comparing the standardized estimates, the estimated effect of direct participation in professional development was 1.5 times larger than that of effect of exposure to peers' expertise gained from their year 2 professional development.

Finally, the estimated effect of network exposure to peers' expertise gained from their year 2 professional development was statistically significant ($p < .05$) for teachers in the highest frequency group. Moreover, the standardized estimate of exposure to colleagues' expertise ($\beta = 0.258$) was larger than that of direct participation in professional development, which was not statistical significant at the 0.05 level ($\beta = 0.160$, $p = .085$). Although the high-frequency group declined in their average level of implementation of writing processes instruction (table 3), within this group, if a teacher is highly engaged in professional interactions with former professional development participants, she would have increased the frequency of writing processes instruction from year 1 to year 3.

Regarding the comparison of estimates across these three groups, the association between professional development and instructional practice in the

TABLE 6

Differential Effects of Professional Development for Teachers with Different Baseline Frequencies of Writing Processes Instruction

	Low (n = 147)		Intermediate (n = 153)		High (n = 131)	
Variable	Estimate	Std Est	Estimate	Std Est	Estimate	Std Est
Direct participation in professional development in year 3[a]	.024**		.013**		.006^{+}	
	(.012)	.203	(.005)	.214	(.004)	.160
Network measure of the exposure to colleagues' estimated expertise gained from year 2 professional development[b]	.232***		.104		.163*	
	(.073)	.316	(.075)	.145	(.069)	.258
Prior writing processes instruction in year 1	1.025**		.465**		.597**	
	(.339)	.256	(.162)	.252	(.182)	.278
Being an ELA teacher in year 3	.870*		.784***		.411	
	(.452)	.168	(.227)	.317	(.216)	.172
Being a female	−.167		−.017		.189	
	(.160)	−.086	(.185)	−.008	(.259)	.066

Years of working at the current school up to year 3	.000		−.002		−.006	
	(.160)	.004	(.012)	−.015	(.013)	−.046
Being a coach or teacher consultant in year 3	.267		−.279		.272	
	(.350)	.061	(.344)	−.070	(.327)	.070
Having a master's degree or higher in year 3	−.197		−.196		.041	
	(.167)	.152	(.178)	−.091	(.225)	.018
Perceived pressure on improving student performance on state writing assessment in year 3	.105		.019		.086	
	(.063)	−.104	(.061)	.026	(.071)	.117
R^2	.368		.336		.424	

NOTE.—Std Est = standard estimate; ELA = English language arts. Standard errors are included in parentheses. School fixed effects were estimated but not included in this table.

[a] Estimate is statistically larger for low group than others ($p \leq .05$).

[b] Estimate is statistically larger for low group than others ($p \leq .01$).

$^{+}$ $p \leq .10$.

* $p \leq .05$.

** $p \leq .01$.

*** $p \leq .001$.

low-frequency group was significantly larger than that in the other two groups, including both the effect of direct professional development ($p \leq .05$) and the indirect effect through interactions with former professional development participants ($p \leq .01$). The estimated direct effect of professional development for the intermediate group did not significantly differ from others, nor did the estimated indirect effect of professional development disseminated through collegial interactions for the high-frequency group.

Discussion

The results from this study support the idea that organized professional development can have both direct and indirect influences on teachers' practices. We found evidence from this study that the duration of content-focused professional development was associated with increases in the level of writing processes instruction overall, indicative of a direct influence on teachers' self-reported practices. We also found evidence that teachers' exposure to colleagues' prior professional development had an indirect impact on their instructional practice. That is, teachers who interacted with colleagues whose practice had changed as a consequence of participation in year 2 professional development in writing changed their own practice after having received help from those colleagues on matters related to writing instruction.

Furthermore, we found support for a developmental account of how teachers learn from professional development. In particular, in professional development related to writing processes, teachers who engage in those instructional practices less frequently may be more likely to change their instructional practices when they participate in organized professional development than their colleagues who use those same practices more frequently. By contrast, for teachers who engage in the target practices most frequently, interactions with colleagues who formerly received professional development are more strongly related to increases in practice than direct participation in professional development. Finally, both direct participation in professional development and the indirect exposure to professional development through collegial interactions were stronger predictors of current practice (controlling for other factors) for teachers with initially lower frequencies of practices than for their colleagues with initially higher frequencies of these practices. Caution should be used in interpreting this finding, however, because of the regression to the mean in the overall sample, as illustrated previously.

Importantly, it is not just any collegial interaction that accounts for variations in teachers' practice. Our models take into account the professional development received by colleagues from whom individuals received help. Teachers' own instructional practices in writing changed more when they received help

from colleagues who themselves benefited from professional development. The association between network exposure to colleagues' professional development and the teacher's own instructional practice change could be interpreted as indirect effects of professional development provided by the Local Writing Partnership sites. Economists of education call such effects spillover effects, and they have observed such effects on more distal measures of both interactions and outcomes (e.g., shared school context and student learning gains; Jackson and Bruegmann 2009).

Finally, the direct link between organized professional development and the teaching of writing processes was relatively small and, for some groups of teachers, smaller than the effects of collegial interaction. This finding is consistent with what has been reported in the overall evaluation for the measure of writing processes (Gallagher et al. 2011). The variation in focus across partnerships on writing processes overall, as well as on specific writing processes, likely contributed to this finding (see Gallagher et al. 2011). It is important to recall that such variation is at least partly a function of the codesign process: Local Writing Partnership sites are expected to adapt their offerings for professional development to the particular needs and goals of schools.

Study Limitations

A principal concern with the data from the study is that they rely principally on teachers' self-reported professional development hours and instructional practices. Teacher self-reports can be subject to bias, and to the extent that teachers are reporting about practices related to the focus of professional development, socially desirable responses may become readily apparent to teachers, leading to higher estimates for weights of predictors in the model (Schwartz 1999; Schwartz and Oyserman 2001). Self-report data may be particularly problematic for measuring changes in the quality of instruction rather than its quantity. Professional development activities often target quality rather than quantity; moreover, teachers may have limited say over how much time they can devote to particular activities because of prescriptions from standards and pacing guides. Our analyses provide little insight into this important purpose for professional development activities.

Second, we caution that this analysis focused on the partnership schools and not on both partnership (treatment) and comparison schools in the larger evaluation study. In the larger study, teachers from both groups of schools increased the frequency with which they engaged students in different writing processes; comparison teachers had some access to (state- or district-mandated) writing professional development. In the evaluation to date, researchers have found no statistical differences between the two groups with respect to adoption

of a process approach to writing (Gallagher et al. 2011). As such, we cannot draw conclusions about the overall efficacy of NWP professional development. Further, we are limited in making strong causal claims for the observed relationships within the treatment group. However, the natural variation in schools' theories of action, exposure to professional development at the teacher level, and instructional practices provided a unique opportunity to explore relationships that could guide future designs for professional development.

A third important limitation is that although our models incorporated estimates of what colleagues with whom a teacher interacted gained from participation in professional development, it is likely that in receiving help from colleagues, teachers benefited from more than just what was learned by their colleague from professional development. Teachers' expertise in practice develops over many years, as a function of experience and often also as a result of participation in multiple reform efforts (see, e.g., Coburn 2004). When giving and receiving help, colleagues are likely to draw on any expertise they have developed that is relevant to the situation at hand. So although we can say that the effects of collegial interaction that we have modeled are indirect effects of professional development because we considered expertise gained from it, our analysis would have been improved by having a better understanding of the content of those interactions that were consequential for teachers. Qualitative data on these interactions would have helped us develop such an understanding.

Finally, it is also the case that one way that professional development may produce effects is by fostering more collaboration among teachers. Indeed, there is some evidence that in the larger evaluation study, and in some schools, that is the case (Gallagher et al. 2011). Even so, more collaboration by itself may not be sufficient to change practice; our models suggest that estimated expertise and frequency of interaction both matter. Future studies should employ mixed methods that include but are not limited to social network data on teachers' interactions.

Conclusion

This study illustrates how social network analysis can help illuminate how collegial interaction can augment the effects of professional development. As a methodology within studies of the effects of professional development, fitting social influence models to data that incorporate social network data and data on teachers' exposure to professional development allows researchers to examine simultaneously the direct and indirect effects of professional development. In addition, social network analysis allows researchers to analyze how

attributes such as what colleagues learned from professional development may be help determine the effect of collegial interactions on a teacher's practice.

There are, to be sure, some important trade-offs in relying on quantitative modeling alone to analyze direct and indirect effects of professional development. Without knowing the content of specific interactions, it is difficult to know whether indirect effects are related only to expertise gained in professional development or from expertise that colleagues have accumulated over many years. In practice, both kinds of expertise may matter, but without qualitative data on interactions, there is no evidence to support that claim. Mixed-method studies that include shadowing teachers and that also include social influence models may be particularly valuable for investigating further the direct and indirect effects of professional development.

Subtantively, this study opens up the space of mechanisms by which professional development might predict changes to instructional practice within a practice-focused theory of teacher learning to additional possibilities for design. The findings invite consideration of developmental perspectives, as well as consideration of the informal social structure of schools, in planning professional development. The findings also suggest ways that collegial interaction could augment the direct effects of professional development in ways that extend its reach throughout a school in productive ways. As such, while the links between the different forms of learning and practice that were observed are small, they point us in a promising direction as a field.

Notes

1. We examined the impact of other factors that might reduce or invalidate the effect of year 2 professional development (PD) contact hours on instructional practices in year 2. By including all possible measured confounds, the *R*-squares of the estimation model did not increase significantly, and the coefficients of PD did not vary significantly. Therefore, the estimate of PD coefficient is relatively robust to those alternative model specifications.

2. We chose fixed effects rather than random school effects in hierarchical linear models (HLM) because the number of schools is relatively small ($n = 20$). When we run an unconditional HLM model to gauge the distribution of variance across these two levels, teacher (0.04) and school (1.71), the school-level variance only explained 5.3% of the total variance (0.04/(0.04 + 1.71)). The chi-square test for school-level variance was not statistically significant ($p = .06$). Second, the fixed effects model appropriately controls for unique school characteristics, which fits the purpose of this study. Although HLM can achieve almost the same result by using group-mean centering (Raudenbush 2009), this study focuses on estimating and demonstrating intra-organizational mechanism. Our analytical focus is at the teacher level within the school. In addition, even if we run the analysis by using random school effects in HLM as articulated in the table 5 note, the results would not alter any of our inferences.

3. Exemplary SAS codes are included in our online resources at https://www.msu.edu/~kenfrank/social%20network/influence2.sas.

4. Regression to the mean can be due to different reasons. For example, it may be a result of (1) measure errors of the instrument, (2) a phenomenon wherein the extreme responses on the measure at the first time point are likely to become close to the population mean at the second time point, which may have nothing to do with the experienced treatment, or (3) random errors.

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