Networks of Change: Learning from Peers about Science Teaching

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Abstract

Rapid changes in the knowledge base of science raise challenges on how to disseminate new knowledge and associated pedagogical practices to pre-college teachers. Accelerating that process by seeding knowledge in a network for dissemination and adoption is one aim of the 'EnLiST' NSF-funded project on entrepreneurial leadership in STEM teaching and learning. As part of that initiative, a study was conducted to explore how teachers' networks support learning about new teaching practices. Questionnaire and interview data address how and from whom teachers learn about the teaching of science. Results show that information about science teaching techniques is of primary importance, most trusted from those who share the common experience of the classroom. New science content from wider contacts is 'refreshing', but most valued when tied to teaching practice. Classroom management, matters external to their school, and administrative matters also form learning networks. All learning is best received in amounts that fit 'in just as much time as I have'. Results help understand how communication practices fit with existing cultural practice and teacher learning, how such interaction may be examined from a social network perspective, and how technology may support such networks.

1. Introduction

Science is a set of rapidly expanding fields, with new knowledge and practices continuously appearing. These rapid changes present challenges on how to disseminate that knowledge among pre-college teachers and advance pedagogical practices. While it might be possible to reach every teacher in every school with professional development, the magnitude of such an endeavor makes this an unworkable ideal. An alternative is to seed knowledge in a network in such a way that individuals promote the further dissemination and adoption of new knowledge and practices. This is one aim of the EnLiST project (Entrepreneurial Leadership in STEM Teaching and Learning), funded by the US National Science Foundation, and undertaken in the context of a five-year large-scale Math and Science Partnership.

EnLiST engages teachers in three-year professional development program aimed at building their science context knowledge and pedagogical repertoire, as well as entrepreneurial skills and habits. The overall goal of the EnLiST program is to develop entrepreneurial science teacher leaders who recognize and act on opportunities to initiate innovative science teaching in their classrooms, and take initiative toward spreading those innovations in their schools and districts.

In this context, entrepreneurship entails making contact with others, demonstrating and encouraging exposure to and use of new teaching techniques such as those learned at EnLiST development seminars. As such, the success of such entrepreneurial practice is tied up with the way information circulates among teachers and what local conditions constrain and/or facilitate such exchange. Given that one of the major foci for EnLiST is the dissemination of information and innovation, we are interested in understanding the way social networks support such exchanges, and, from an entrepreneurial perspective, how experts and colleagues can serve as resources for initiating and sustaining innovative practices. Thus, as part of the overall EnLiST project, a study was conducted to explore the way teachers learn about new teaching practices, addressing the question: What do teachers learn from each other that supports their teaching of science and their working lives?

The focus in this paper is on understanding networks of learning about the practice of science teaching. Data on learning networks was obtained from participants in the EnLiST project. Results provide details on the size and composition of social networks that support teachers in learning about science teaching, and provide insight into the social networks of information exchange among teachers, including details on what kind of information is most valued, who teachers trust to provide such information, and

978-1-4799-2504-9/14 $31.00 © 2014 IEEE
DOI 10.1109/HICSS.2014.21

how exchanges happen within school contexts. Together these data provide a picture of how teacher networks support learning about science teaching. Results provide input for understanding how entrepreneurial practices fit with existing cultural practice and teacher learning, as well as outline how such interaction may be examined from a social network perspective.

The next section situates a social network perspective on learning, outlining the different ways learning can be considered from a relational view, i.e., as demonstrated in the interactions between people in a network. Of particular interest are how entrepreneurial behaviors may be evident in peer-to-peer teacher networks and what characteristics of the relationships between teachers facilitate information exchange and transfer of innovation. To study such behaviors, we asked teachers what they learned from others that supported their teaching. Because participant teachers come from different schools, we concentrated on a teacher-centric view. Our aim was to assess the current state of information exchange about science and science teaching, including what kind of information is important and who best provides it. This approach allows for understanding information dissemination activity in schools in support of improving processes of teaching and learning where needed. As discussed below, results reveal what and who matters for receiving and adopting new practices, provide insight into the facilitators and constraints for such exchanges, and suggest routes for getting the right type of information flowing through the right channels.

2. Social Networks and Learning

The aim of any teaching and learning project is to pass on information in such a way that it is incorporated into individual understanding and/or practice. But when we step out of the classroom environment, we leave behind the assigned roles of teacher and learner, and expected directions of learning from master to novice. We are then challenged to find out *who teaches* (or learns from) *whom, about what, and how*. A social network approach provides the framework for asking questions in a way that explores the exchange of resources between members of a network: who talks to whom about what. Interrogating network structures shows what resource exchange (or combination of resources) holds the network (and/or its subcomponents) together.

The idea that networks are powerful platforms for learning has been supported for a long time in studies outside schools, but only more recently for the school context [28][10][11][13][12][21]. An accumulation of resources in a network, and their mobilization to address needs, sustains the capital (e.g., social, expertise, know-how) that makes for effective and successful groups and communities. Research on the way information circulates in a network shows not only how resources are embedded in a network, e.g., in its social capital [22], but also how and what transfers from one person or part of the network to another [22][18][19][20].

Learning is, of course, more than just receipt of information. It also entails taking up and incorporating that information into personal understandings, into practice and further dissemination. Research on networks and adoption of innovations [27][34] shows that relationships between people make the difference between just hearing information and being convinced of the worth of adopting a suggested practice. Thus, in the context of learning we are equally interested in how and between whom information is exchanged.

A social network is evident from the connections among *actors* who are connected or *tied* to each other by the maintenance of one or more social *relations*, i.e., specific kinds of interaction [2][30][36]. This can be analyzed as a *whole network* or as a *personal* or *ego-centric network* that summarizes the range and extent of personal network connections [6][38].

Both circulation and uptake of information (i.e., learning) can depend on the nature of the interpersonal tie between people, with information from trusted sources accepted and used more readily than that from strangers or acquaintances. A key distinction exists between 'strong tie' relationships maintained with friends, co-workers and family, and 'weak tie' connections with those known less well. A number of well-known studies have shown that weak tie connections are good for finding information different from that available through friends. From these studies have come the long-standing realization that awareness of innovations [27], access to new information [39], and readiness to recognize and adopt new practices (e.g., having 'absorptive capacity'[8]), depend on a diverse communication structure and engagement with people and ideas outside the local network [26][23]. Looking from a whole network perspective, studies also show that the configuration of the network – who is connected to whom – determines the process and opportunities that exist for hearing and learning about new practices, preparing for change, and positioning to effect change (e.g., in bridging 'structural holes', [5][18]; for a longer review of these studies in the context of teacher learning, see [14]).

By contrast, persuasion to adopt an innovation [27], commitment to an agenda, and provision of social support are more likely to be accomplished through connections with strong ties, people who know each other well and are more like each other [25][35][37]. A strong tie suggests a common understanding of contexts and practices, as well as greater knowledge of the person with whom the relationship is maintained. Thus, exchange of information, for example, between teachers in the same general subject area or from the same school, can be more tailored to the particular pairing involved, for example, skipping unnecessary contextual information or extending the discussion of points known to be unfamiliar or difficult to convey. In this way, mutual understanding speeds exchange of new information, decreasing the work the information provider needs to do to convey it [7]. And, it increases the receiver's trust that this information is relevant to their personal circumstances and, thus, the likelihood of the information being incorporated into practice. This initial understanding feeds back to the provider who can see that their efforts in conveying the new information have benefit to their friend or colleague, encouraging further exchange and interaction. While perhaps not as visible to the individuals involved, further benefit accrues to the network as new practices are incorporated and tested across the network, and as the strong ties between people continue to make it desirable to share results with friends and colleagues, building an organizational culture of sharing.

3. Learning from a Network Perspective

Approaching learning from a social network perspective opens up a number of ways to examine learning. We can think of learning as the content of a single relation that connects people, e.g., "I learn from my teacher." Or, we can think of learning as the characterization of the tie, based on multiple, contextually-determined relations. Thus, a learning tie may emerge with a colleague because he or she provides suggestions about teaching, but also career advice and social support. At a network level, learning can be a characterization of the outcome of relations, e.g., as a group becomes a learning community; or it can be seen as the network outcome of relations, e.g., as the social capital that results when the sum of what a community knows is greater than that held by individuals. Since we share exposure to events, news, regional and national norms and laws, at a societal level we may consider learning as contact with common experience (e.g., our common experience with school and educational systems), and what we might call the ambient influence that results in informal and 'ubiquitous learning'[9].

These different takes on learning help in understanding how social networks support learning. At a more practical level, what we discover about learning relations can be taken as input for design of more effective information dissemination and learning support within a network. For example, network relations may show that face-to-face meetings are the most effective way of hearing about and gaining understanding of a new domain knowledge, but a web site is more effective for supporting common knowledge (for more on this, see [21]).

Interestingly, while attention to a social network perspective on learning and transfer of information and expertise in the context of schools has recently been on the rise, this perspective has yet to appear in studies related to the professional development of science teachers, or for effecting change in instructional practice as a result of engagement in such experiences. A search of the science education literature did not return any studies with an explicit or systematic focus on social and/or learning networks. This is the case despite the fact that science teacher educators and researchers have been attuned to the value of teacher relationships and collaboration, and their importance to the realization of the potential of professional development in effecting change [1][3]. Research into the ways science teachers' social networks interact with their learning and/or function within the spheres of the adoption and transfer of innovative instructional practices should prove very promising to efforts aimed at effecting transformational change in precollege science teaching and learning.

4. Purpose and Research Questions

As noted, this study is part of a larger research effort examining how innovative and transformative practices in pre-college science teaching can best be initiated, disseminated and adopted within school districts. As a starting point for the social network analysis of these practices, this study aimed to provide an understanding of the kinds of relations that characterized learning ties, and the relationships between teachers that support information exchange and adoption of new practices. Results reveal ways in which some formal practices in the delivery of information are at odds with teachers' practices of learning informally from colleagues, providing input for future dissemination and initiation efforts.

We took a personal network perspective to explore these key questions about learning and social networks asking: What constitutes a learning tie for science teachers? Who maintains learning ties with whom? and What authority, practices, or structures help to start or maintain ties?

In ongoing studies, the larger district context of the network is being examined to see how the network configuration of ties affects resource flow among teachers in the school district over the course of the research program [29][40].

5. The EnLiST Project

The focus of the EnLiST project is on the teaching of chemistry and physics in high school and physical sciences in middle and elementary classrooms. EnLiST aims to prepare entrepreneurial science teacher leaders who effectively initiate, participate in, and/or lead innovations that transform the quality of science teaching in their own classrooms, buildings, and/or school districts. The program entails a three-year engagement in an intensive, long-term professional development program, which features a connected series of intensive summer institutes and courses focused on science content, pedagogy, and entrepreneurial leadership. Incentives for participation over the three years include: at least $3,000 in stipends; high quality professional development in science content, pedagogy, and leadership; opportunities to earn graduate credits; and a Leadership Certificate from the University of Illinois (http://enlist.illinois.edu/about).

Teachers from core partner school districts apply for and join the program (if selected) in a cascaded structure. First, a group of high school chemistry and physics teachers from a district (the 'core' group) joins the program in Summer I for content and pedagogy institutes; in the following school year they continue to work on an innovative individual project. The same core group returns in Summer II for nanotechnology and entrepreneurial leadership institutes and is joined by a group of middle science and elementary school teachers (referred to as a 'cascade' group). The cascade group engages with a physical science institute and then connects with the core group during the entrepreneurial leadership institute to plan collaborative projects for the coming academic year.

The EnLiST partnership supports teacher projects through a host of resources as long as teachers show they have secured some resources themselves, and 'resources' refer to more than monetary investments. Indeed, one of the challenges for the project is to help teacher leaders realize that 'resources' available to them include, among other things, 'others' within the partnership (e.g., science teachers within a building or across the district, university faculty with expertise in STEM or education fields, and community member volunteers). Teacher projects, which are implemented and reported on during the third year and beyond, create spaces for teacher collaboration and innovation, as well as opportunities for leadership that are an alternative to traditional models prevalent in schools (e.g., science department head or science curriculum coordinator). The EnLiST cycle is repeated with a total of three core and cascade cohorts separated by a one-year lag. Thus, EnLiST engages ever-increasing numbers of science teachers from within the core partner school districts both to create substantial mass that endorses change, as well as an expanding network of teachers who could ultimately serve as additional resources for innovation. Building social networks is both a major component of EnLiST and also part and parcel of the entrepreneurial mindset and practice.

This paper reports on data collected from the core I, cascade I, and core II EnLiST Fellows. Informed consent was obtained from participants in accordance with institutional review board protocols.

6. Method

Data for the personal learning networks was collected using a questionnaire completed by 54 EnLiST participants. These included all 14 core cohort I (summer 2009) and all 13 core cohort II (2009) high school science teachers, and 25 of 31 cascade I (summer 2010) middle school science and elementary teachers. The cascade cohort I teachers come from the same school districts as the participant core I high school teachers. Questionnaire administration was followed by in-depth interviews with 14 of the 16 members of the first EnLiST cohort.

As noted earlier, the questionnaire used in the study asked respondents about their interactions with others related to learning about science and science teaching. The questionnaire was first tested in a pilot study with two non-EnLiST teachers. The researchers and the two pilot participants discussed the understandability of the questions and the format of questionnaire design. The pilot version asked about 'learning about science' separately from 'learning about science teaching.' Feedback during the pilot study provided an early insight into the kind of knowledge science teachers valued. These teachers let us know that learning about science and about science teaching are so highly intertwined that participants could not separate who they learned from about science content from those they learned about science teaching. Thus, following the pilot, these two aspects of learning were combined.

The questionnaire first asked participants to identify "the 5-8 people you communicate with most frequently about your area of science and science teaching," including fellow teachers, but also people met elsewhere. Participants were then asked to describe briefly what *they learned from* the five people with whom they communicated most frequently about their area of science and science teaching. Thinking of these five, and up to five more, they were then asked to describe briefly what *they thought these individuals learned from them* about science or science teaching.

These data provide information on the size and composition of teacher networks for learning about science and science teaching. Although restricted to an upper limit of 8-10 people, the number of people named still provided insight into the range and extent of the network for learning relations, e.g., whether a focal individual has many others to turn to for help and learning or whether their network is limited in terms of learning sources. Additionally, asking about the direction of learning shows how information flows to and from the focal individual and members of their close learning network, and thus, whether the individual acts as a major source (giving help) or recipient (receiving help) of information, expertise, etc., related to teaching. Asking what was learned provides insight into the kinds of exchanges that comprise a learning tie.

The number of five to eight people was chosen in keeping with practice in social network name generator surveys [24]. It is expected to adequately capture relationships that include discussion of 'important matters' [4], i.e., referring to stronger, personally meaningful ties rather than weak tie connections. In a similar study to ours, in 2009, Roxå and Mårtensson [28] asked 106 university instructors how many people they engaged with in conversations about teaching and learning, without imposing an upper limit. In their sample, 83% reported 10 or fewer partners; engineering instructors averaged 5.4 conversational partners, and social science and humanities instructors somewhat higher at 8.4 and 8.2 partners. These results suggest that asking about 5-8 others is likely to have adequately captured important or significant discussions around science teaching.

Coding Responses. To evaluate the types of learning that characterize ties for these teachers, the answers about what they learned from others, and what others learned from them were evaluated and code for common themes. A *content analysis* was conducted by the primary author; it involved a careful reading of the responses and derivation of codes for the types of interactions reported. Five codes were derived relating to what is learned by participant science teachers:

- T: science *teaching* techniques, e.g., "helping to develop chemistry curriculum", "teaching strategies", demos, "best practices", "new ways to teach students"
- C: science *content*, e.g., "physics concepts", "water filtration", "resources"
- M: class and behavior *management*, e.g., "classroom routines", "classroom management techniques"
- E: matters *external* to their school, e.g., "Science Olympiad", "community impact", district policies
- A: school and *administrative* function, e.g., "administrative & political information", "leadership", "staff development"

Once the codes were determined, responses were assigned one or more of these codes, providing a coding of the learning relations that tie these teachers in their science teaching learning networks.

The network relations are one source of data used here. As noted above, a second source of data is the set of in-depth *interviews* conducted with teachers from the first EnLiST core cohort [14]. Interview data and subsequent analyses were conducted from a grounded theory perspective [33], following the interviewee's lead, while staying focused on the object of study, i.e., the social processes that support learning and diffusion of innovations, and processes that lead to construction, maintenance and expansion of teacher's learning networks and innovation networks. Interviews concentrated on: what facilitates or impedes learning network connections; how learning happens; perceptions and practices related to learning for the profession; experiences with innovations in teaching and learning; what relations make up "learning"; and how interpersonal contacts influence learning.

7. Teacher Learning Networks

The data collected provided a view into the learning network for participant science teachers. Individual's responses about their learning network, and the greater detail provided in the interviews, allowed us to put together a view of teacher learning relations and networks. The following describes the results with attention to what constitutes a learning tie for these teachers, and what practices or structures serve to help start and maintain learning ties.

Learning Ties. In keeping with the size of the network asked about, the teachers reported an average of 5 others with whom they learned (high school teachers, cohort one: 5.9 others; cohort two: 4.5; middle and elementary teachers cohort: 4.72), with a range from 0 (no contacts) to 11, median 3. In all, the teachers listed 272 learning ties. Among these, 10 groups or organizations were noted as learning sources, as well as six cases of listservs, websites or the Internet as learning sources. As the focus here is on person-to-person ties, the following addresses *256 pairs.*

Table 1. Distribution of 'learn from' relations

Relation	n=256 (100%)
Teaching techniques (T)	173 (68%)
Science Content (C)	72 (28%)
Classroom Management (M)	32 (13%)
External Matters (E)	27 (11%)
Administrative functions (A)	17 (7%)
None	9 (4%)

Pairwise connections were coded using the five codes noted above. A majority of ties (68%) included learning about science teaching techniques. Other relations were maintained by far fewer pairs, from 7-28% (Table 1). For 9 pairs, the respondent indicated no 'learn from' tie; these individuals may have been named because they learned from the respondent.

Single vs. multi-threaded ties. A single relation may be the only connection between the respondent and their named alter, or several relations may be included in the same overall 'learning tie' maintained by pairs. In considering the make-up of a learning tie, and of learning networks, it is of interest to see what relations combine with which others. Where relations do not combine, they show that different networks support different kinds of learning, e.g., for learning about teaching techniques versus science content or class management.

Considering only those with some kind of tie, the 247 pairs maintained 321 relations in total for an average of 1.29 types of learning from others. In 74% of cases only one type of learning relation was present (183 were coded with one relation; 56 with two, 6 with three, and 2 with four relations). Thus, the first observation is that learning is generally *single-threaded*, i.e., concentrated around one kind of learning. While this could be an artifact of the data collection method, which asked for a brief note on what was learned, the single first response is likely to indicate the most significant kind of learning and a lack of ambiguity in providing an answer. Hence, we may consider this kind of learning to be, from the respondent's point of view, the strongest relation connecting the pair.

Table 2 provides details on the way in which relations co-occur for ties with one or two relations only. Across the diagonal are the 183 single-threaded learning connections. Where multiple learning relations are maintained by a pair, learning about teaching techniques still predominates. Reading across the table: when two relations are maintained, 'teaching techniques' combines with 'science content' in 25 cases, with 'classroom management' in 12 cases, 'external matters' 4 cases, and 'administration' 6 cases. For the remaining 8 multi-threaded ties not given in the table, all include teaching techniques, with seven combining this with content, three with external matters and two with administrative function.

Thus, the picture of teacher learning networks is of interaction dominated first and foremost by ties that help in learning how to teach science in the classroom. Second to this is learning about science itself, with 50% of those ties maintained with the same people from whom they learn about 'teaching techniques' (32 single-threaded 'content' ties vs. 25 double- and 7 multi-threaded ties that include 'content' and 'teaching techniques'). Class and behavior management is third most frequent, with nearly half (48%) combining this with learning about 'teaching techniques'; followed by 'external matters' and 'administrative' (46% and 71% held in common with 'teaching techniques').

Table 2: Distribution of learning relations

	Teaching	Content	Mgt	External	Admin
T	**118**	25	12	4	6
C	--	**32**	3	4	1
M	--	--	**14**	0	0
E	--	--	--	**14**	1
A	--	--	--	--	**5**

Single-threaded ties are in bold on the diagonal (n=183); double-threaded, non-bold (n=56); the 8 multi-threaded ties not given in this table are: CTA, 3; CTE, 2; CTM, 1; CTEM, 1; TEMA, 1.

Who learns what from whom. While learning about teaching techniques dominates, there are some aspects of learning that derive from different networks of connection. Examining who maintains ties with whom may show whether there are identifiable attributes of the actors that distinguish those providing learning about teaching techniques from those providing other kinds of learning.

To explore this possibility with the data at hand, we examined whether the respondent and the person named as someone they learn from came from the same school or for outside the local network. Lists of teachers at district schools were used to identify the people mentioned. Of the 247 pairs reporting a 'learn from' relation, a school could be identified for 118 of the actors named by the respondent. Of these, 63% (75) were at the same school; 37% (44) at different schools.

Table 3: In-school and out-of-school connections by relation (n (%))

	T	C	M	E	A	*Total*
In	30 (35)	13 (34)	4 (40)	5 (31)	1 (11)	**43 (37)**
Out	55 (65)	25 (66)	6 (60)	11 (69)	8 (89)	**75 (63)**
All	85	38	10	16	9	**118**

Interview results, reported below, suggest that learning about teaching technique is trusted more from people with similar experiences. Thus, we might expect that teaching ties are more prevalent among those in the same school than outside. Are ties inside a school more likely to be about science teaching techniques than content? As shown in Table 3, 63% of ties are maintained with people in the same school, and this percentage is fairly consistent across most of the relations. Only learning about administrative functions shows a real difference, although with the caveat that numbers are small. In this case, 89% of administrative advice came from in-school ties. While further exploration is needed on what draws individuals to connect with in-school versus out-of-school others, the results at this point suggest it is not the kind of information exchange that matters except potentially about administrative activity. Some further insight may be gleaned from the interview results discussed below, but at the tie level there appears to be no particular overriding relational content that drives out-of-school connection.

8. Interviews

Interviews with 14 of the 16 first cohort of teachers provided insight into the answers contained on the questionnaire, and into the teacher and school cultures that affect conditions for learning and innovation (see also [14]). The purpose of the interviews was to explore the social processes that lead to the construction and development of learning networks and educational entrepreneurship among teachers from the schools participating in EnLiST. Interviews pursued questions about learning as it related to acquisition, practice and dissemination of knowledge about the teaching of science, and innovative practices around science teaching. The discussion covers the common themes revealed in the analysis, organizing this by what is learned from whom, and how local conditions affect the flow of knowledge.

In considering our results, we find they echo those of Roxå and Mårtensson [38] that explored the network of colleagues with whom university instructors discussed teaching and student learning. The researchers identified three key themes in peer conversations: *private conversations*, with author commentary and respondent quotations showing that such conversations also often arose spontaneously and 'almost never' take place in formal meetings; *trustful conversations*, noting mutual respect as an important attribute between teachers, and with an emphasis in conversation on problems arising from actual teaching practice; and *intellectually intriguing conversations*, which the authors used to mean conversations that addressed real issues around teaching rather than small talk or emotional support. Roxå and Mårtensson used the term 'significant' to describe the conversations and social networks involved, capturing what Burt and others might refer to the 'important matters' that we discuss with our 'core networks.' [5][24] While our terms may differ slightly from those used by Roxå and Mårtensson [28], it is evident that we are observing the same phenomenon. The quotations from Roxå and Mårtensson's participants sound very much like those from our interviews with high school teachers. Thus, we believe that we are addressing a general trend in learning about teaching practice that holds across level of education.

9. Information Routes

What and who. Our interviews with teachers yet again highlighted the importance of learning about strategies, techniques, and resources used in and for the classroom, confirming the primary importance these teachers place on learning about science teaching. As one interviewee put it, "pedagogy and pedagogical content is more important that just content." While it is known that discussions with a core network can entail important matters, the evaluation of the content of learning ties discussed above, and the interview data here, allowed us to pin down more exactly what 'important' means in the context of professional teacher networks.

What is most important to teachers is knowledge highly tied to their profession: its practice, the conditions of teaching, and the experience in the classroom, i.e., pedagogical content knowledge [15][31][32]. Our network questions and interview data also reveal something more about the importance of *who* provides this information. Like Roxå and Mårtensson, we find that a key dimension in learning from others is the presence of a trust relationship between discussants, with trust explained by interviewees as being built with someone who has understanding and experience similar to theirs. We can describe these as strong ties, build on homophily, common ground, and shared understanding. While learning from non-teachers or outside experts is accepted, the preferred information route is from those who do the work and understand the environment. Trust comes from similarity in experience, but also trust that the technique has been tried in a situation similar to their own.

- I would like to hear from other teachers if they had success doing things, what they do… I would have much more believed in input from people teaching physics and how they had success with students.

Common ground provides benefits as it reduces the joint work teachers have to do in sharing information.

- If I have a kid that's struggling, and I know that teacher has connected with that kid, we'll talk.

Common philosophies and experiences make the information not only more relevant, but more closely tied to their own understanding and local conditions. Exchanges such as these are 'worth the time',

- Their teaching methodologies, teaching philosophies have meshed with mine, so that makes it worth my time to discuss teaching with them.

"In just as much time as I have" learning. This kind of knowledge is passed along through person-to-person contact rather than through seminars or online sources. Interviews reveal the importance of just-in-time learning, or rather 'in just as much time as I have' learning. Participants noted the informal, *ad hoc* nature of such learning, achieved in the hall, in 60 seconds, or five minutes. Because this type of learning is unplanned and serendipitous, physical and temporal co-location are important as it offers the opportunity of exchanges:

- We both have our first hour free, first thing in the morning, and then after school. After school, we are the two teachers that stay really late. Kind of handy, and our room, they are really close together, so we talk quite a bit.
- After school some of us just get together and talk. How is your day? What went well? What things did you try?

Closeness helps, and distance impedes.

- I'm kind of isolated, it is kind of lonely, because I can't just walk down the hall and talk to someone…. Everybody is a block away.

While some can control their schedules, physical and temporal co-location is often under the control of others, rather than of the individual teachers themselves. Distributed locations are one issue, as in the comment above. But temporal schedules are an aspect that might be addressed at an administrative level. One teacher suggested this as a way to facilitate interaction and knowledge sharing:

- If it's at all possible, trying to get common prep and common lunch periods helps, but it's difficult to do from administrator's standpoint. But that's one aspect of it; if they pull that off, build at least some [common time] during the day.

Weaker ties. Strong ties are not the only source of learning. Weak ties with teachers at other schools, members of the EnLiST cohorts, and conferences and workshops are important for learning, and particularly 'refreshing' new information:

- Anytime you can take a break from your regular routines and go to other teachers and get some fresh ideas, it's worthwhile.

What is learned can range from demos to science techniques to field domain knowledge:

- Sometimes it's a demo I haven't seen before, or a new way to do a demonstration, or may be it's a lab I've done before, but their technique is better, quicker, faster, more economical, more effective. Sometimes it's seeing new information like [how] chemistry and physics is changing, that's helpful.

Science content. What of the science involved? Are science teachers interested in learning about science domain knowledge? The answer is heartily yes, *but*, it is best accepted when connected to practice *and* when delivered in the depth that matches the needs for practice,

- The realization that 'wow, this is simple enough that students can do this.' I can incorporate this in my curriculum.
- When I go [to a professional development opportunity], I try to come back with an activity or demonstration, something I can use in my classroom. It may not be at a deeper level … It'll be just one forty-five minute [session] that just has a really good hand-on activity or really good demonstration.

Matching information to network exchange routes. The purpose of the EnLiST project is to promote innovation and entrepreneurial leadership among teachers. Along one dimension, the project aims to start a cascading effect beginning with summer institutes where science content experts present novel science techniques (e.g., using GPS applications or atomic clocks to teach core physics concepts), which then are revisited during the pedagogical training. The hope is that some of these innovations will be adopted and transformed by participants for use in their own classrooms, as well as for sharing with other teachers. However, the interviews reveal a tension inherent in this structure that may interfere with this model. The tension is between the kind of practice-based information and learning that is part of the strong tie connection between practitioners and the new information delivered by weak-tie, outside experts. The interviews suggest two kinds of mismatch, which present a challenge to the EnLiST objectives and to other projects aimed at effecting transformative change in science learning environments.

First, there is a mismatch between the type of information dissemination and the type of interpersonal connection found to be most useful in the *awareness* stage (weak ties) of adoption of innovations versus the *persuasion* stage (strong ties; [27]). EnLiST presentations are about awareness, given by experts, but with the intent of persuasion. Yet, in these interviews, teachers stressed how much they need to hear from fellow teachers in order to take an innovation into actual use, i.e., to hear from similar others in similar circumstances in order to be persuaded to adopt new practices. On a positive note, this close contact with fellow teachers is precisely the intention of the EnLiST initiative, i.e., to have these teachers become the trusted experts in their schools.

Further, the EnLiST dissemination model has experts present on new content and techniques, with discussion oriented toward scientific inquiry. While many appreciated this opportunity, this kind of information remains at an awareness strategy, removed from the practice of day-to-day teaching. As one of the cohort members commented,

- Yes, there were times when we had interesting discussions about inquiry or things like that. What we were avoiding doing was spending time as a bunch of science teachers talking about how we actually teach physics. We spent a lot of time talking in general about science, students in science education, kind of very generic terms, but never really get into specific about projectile motion, necessary for first year class.

Second, once teachers return to their schools, there is a mismatch between the idea of persuading others to adopt new practices and the norms in schools about help and learning. Awareness strategies, e.g., lectures or the like, are not workable within schools. As one cohort member said about talking to others,

- Discussion starts from their interest, and then it moves forward with letting out how I've been successful with it, and what I've seen as difficult about it and how I've seen it work over time. I don't oversell it. I don't try to claim it to be a magic pill. I try to be honest, how it's been successful with my students.

Further, there is a norm of professional autonomy that results in a lack of desire to influence others. This comes out strongly from many interviews, as exemplified in these comments:

- I'll tell them what I'm doing, but it's up to them whether they are going to do anything with it.
- They know what they are doing … they can make their own decisions.
- They've got to realize there is a problem with what they are doing … I don't need to shove some kind of new technique down their throat.
- It's really up to the individual teacher if they want to try some new idea or not.
- If I thought I had a really good [teaching technique], I'll probably let them know about it, but I probably won't persuade them to use it, because they might have one that's just as good … We don't try to force them to do something.

Overall, these interviews reveal important aspects of professional and organizational life that work together with projects such as EnLiST to affect the reception of new teaching practices.

10. Conclusion and Future Work

This study presented data on the learning networks of science teachers. While not directly addressing media or technology use, the data show an analysis of information exchange that can be used in design of such systems. Together, these data provided an understanding of what constitutes a learning tie for these teachers, and thus what needs to be supported via social media, information sources, social networks, etc., as well as the organizational constraints that affect receipt and use of new information.

In general, examining networks in this way shows first *what matters*. For these teachers what matters is overwhelmingly the learning of teaching techniques for the practice of science teaching and pedagogical knowledge content. Yet, networks also support learning about science content, classroom management, and other educational matters with a focus external to the local context, and administrative function. Second, it shows *who matters*. Here, these are overwhelmingly fellow teachers who understand the needs and demands on in-class practice, have tried techniques in the same contexts and can report on positive outcomes. Outsiders can provide information on science content, but the important aspect for these teachers is the learning about the way that science content can be brought into their daily practice.

The study also shows *how* and between whom information circulates, and thus provides input into how to get the right information flowing through the right channels. Results suggest that new teaching techniques are better accepted through strong teaching tie contacts, again, those who understand and have tried the techniques being promoted. While *awareness* of new science content is well covered by meetings, courses, and workshops, *persuasion* to bring that content into the classroom requires confirmation, demonstrated and verified through practice, and thus again is best received from those with strong teaching credibility as judged by the potential adopter.

The learning networks also point out conflicts in information routes. In particular, the idea of persuading others to adopt a practice that a teacher has initiated appears to be in conflict with norms of professional autonomy. Persuading colleagues to adopt new techniques can be seen as a threat to a strong-tie relationship that has been built on mutual respect and trust in individual autonomy. This presents a challenge for models of diffusion that may rely on expert-novice principles (e.g., disciplinary and/or pedagogical experts working with teachers). Persuading others is neither in the experience nor culture of the environments of the teachers interviewed.

As noted, the purpose of the EnLiST project is to promote entrepreneurial leadership in new science teaching methods and content. These results suggest some social and organizational barriers to such practice, while at the same time pointing out directions in pursuing the overall goal of diffusion of these techniques. Other research in EnLiST is addressing how best to foster entrepreneurial behavior in teachers attending EnLiST institutes. The network data suggest that it may be only after a critical mass of teachers attend and accept a more overall entrepreneurial culture that diffusion will become evident. These results also suggest that working with cultural norms may play an important role in seeing increased entrepreneurial behavior among EnLiST participants and colleagues. Work continues in examining network connectivity change, exploring how, and whether, participation in EnLiST has positively affected collaboration across a whole district [29][40].

11. References

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