Supporting Science Teacher Learning of Technology Integration Through New Models and Tools

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DEDICATION

I dedicate this work to my wife, Patricia Jones. Without your support over the past six years, this work would not have been possible. Thank you for your time, understanding and encouragement.

I also dedicate this work to my parents, Mr. Montel Jones and Mrs. Gladys Jones, and to my mother-in-law and father-in-law, Dr. Juan Astruc and Mrs. Pilar Astruc. Your interest and support were invaluable.

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Supporting Science Teacher Learning of Technology Integration Through New Models and Tools:

Linking Document

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Supporting Science Teacher Learning of Technology Integration Through New Models and Tools: Linking Document

The purpose of this manuscript style dissertation is to examine the processes science teachers engage in for learning about technology integration, and suggest how new models and tools can improve teacher learning in this area. This line of research is intended to provide those who are interested in the processes science teachers engage in for learning about technology integration, such as school leaders and instructional designers, with findings that will enable them to create more effective learning opportunities for teachers, build capacity within their organization, and align the learning goals of the organization with those of their teachers.

Currently, school divisions focus primarily on formal professional development (PD) activities to assist science teachers in integrating technology into their instruction. These activities typically consist of short, one-time workshops with minimal on-going support. While research on effective science teacher PD for technology integration (e.g., Higgins & Spitulnik, 2008) suggests implementing elements such as social support and teacher collaboration, these elements are not yet widely used for science teacher learning of technology integration. However, teachers, despite the lack of organizational support, exhibit many of the suggested elements through their informal and independent learning activities. This tension between what teachers do and what school divisions provide limits teacher learning, wastes opportunities for school divisions to capitalize more extensively than at present on teacher learning, and creates misalignment between the organization's and its teachers' learning goals.

Through our findings, we were able to provide practical suggestions for developing a more holistic teacher learning system for technology integration in science instruction. This proposed system capitalizes on the affordances of specific learning modes to minimize the constraints in other modes, and uncovers new affordances through the synergies created by combining learning modes. As well, the proposed system provides better alignment between teachers' and the organization's learning goals.

Overview

The misalignment between what school divisions provide and the learning activities teachers engage in was identified by an initial examination of the literature and focus group interviews with math and science teachers in several middle schools. We heard teachers describe the additional learning processes they engaged in to better integrate technology into their instruction, and we began to categorize learning activities into three modes: formal, informal, and independent. This description was echoed in the literature for both teacher and general workplace learning. Next, we conducted a more comprehensive examination of the literature and identified an appropriate conceptual framework, detailed below, that provided a lens through which to view the ways in which teachers collaborated to better understand technology integration. We also generated practical suggestions for school leaders on how to develop a more holistic science teacher learning system for technology integration, an element noticeably absent from the majority of emerging research in this area. Finally, we conducted our most micro-focused study in this area and closely examined the learning processes of four science teachers in a single science department in one school during one calendar year. Using a mixed-methods approach, we were able to collect both qualitative and quantitative data

from these teachers, and develop a richer understanding of the learning processes they engaged in to learn about integrating technology into their instruction.

Our research in this area has evolved in parallel with the development of the CANLEAD organizational learning environment. It has provided information beneficial both in CANLEAD's initial design plans and subsequent iterative modifications. This virtual environment brings together school leaders with teachers and facilitates the process of professional development. School leaders can design and implement learning experiences for teachers, monitor their progress, and communicate with them asynchronously. Teachers can collaboratively participate in formal professional development experiences, informally learn and communicate with school leaders and peers, and independently locate and interact with people and resources of interest.

Together these papers represent (1) an initial pilot study for CANLEAD that identifies short-comings of a district-based model noted for its content area specific technology instruction, (2) a review of the literature that identifies where and how improvements could be made to this and other commonly used models and tools, and (3) a year-long, longitudinal, mixed-methods case study of four science teachers during CANLEAD's first pilot year that examines what modes, tools and activities these teachers used to learn to integrate technology. The three manuscripts, each utilizing a different research approach, present a line of research on science teacher learning of technology integration that evolves from a broad view of the topic to a close examination of teacher practices in this area. The three studies demonstrate the evolution of our knowledge in this area, and taken together, provide the rationale, conceptual understanding, and practical knowledge required to assist schools and school districts in

designing, creating, and implementing effective, holistic teacher learning programs for technology integration in science instruction.

Details Of The Three Manuscripts

The first manuscript details an empirical study of current math and science teacher learning of technology integration, and suggests that their system for learning goes beyond the formal PD and professional learning communities (PLCs) provided by their district. Teachers in this study reported using both informal learning activities with colleagues and independent learning activities to extend formal PD experiences. Through an analysis of focus-group interviews, we began to realize the misalignment between what districts provided to teachers and the actual practices teachers engaged in to learn about technology integration. This misalignment results in not only inadequate learning opportunities for teachers, but also a missed opportunity for districts to build capacity within their organization. We identified three interdependent modes of teacher learning (formal, informal, and independent), and illustrated the affordances and constraints of each mode. As well, we began to consider how these modes work together, and how technology could assist in combining these modes to provide a more holistic system of teacher learning. This study also informed the design phase of the CANLEAD project, in which we began to create a model of just the type of holistic system that would support each of the three learning modes, provide more effective teacher learning experiences, and assist district leaders in developing capacity within their organization.

Manuscript two presents a selective review of empirical studies of science teacher learning of technology integration through learning communities. This review allowed us to deeply analyze the literature, and identify both an appropriate conceptual framework

for our work, as well as three models of teacher learning that aligned with the three modes identified in the findings from the first manuscript. The theory of situated learning and legitimate peripheral participation in communities of practice (Lave & Wenger, 1991) was identified as an appropriate lens through which to view these communities in which teachers collaborate to learn about technology integration. The theory defines communities of practice as informal communities that people form as they pursue shared enterprises (Wenger, 1998), and provides a framework to analyze these communities in terms of their (1) agents, (2) activities, (3) communications, (4) development and (5) tools. Through examination of the literature, we also identified three models of teacher learning communities: formal professional learning communities; informal communities of practice; and personal learning networks. Each of these models has unique features that promote formal, informal and independent modes of teacher learning, respectively. An examination of current empirical research on these modes and models, as well as hybrid models combining formal and informal modes of learning echoes the conclusion from the pilot study that a holistic model for teacher learning, incorporating elements of formal, informal, and independent learning modes, should be considered in designing learning experiences to facilitate science teachers' integration of technology into their instruction. Through review of the literature in this second manuscript, we offer a synthesized vision for combining modes as we begin to see that the affordances of individual modes counteract the constraints inherent in others. As well, we also develop practical examples of how to combine these modes in a holistic system facilitated by technology.

Building on the first two manuscripts, the third and final manuscript more closely examines the modes, tools, and activities four science teachers in one department use for their professional learning of technology integration. The four longitudinal case studies of science teachers involved in the first pilot year of the CANLEAD project provided a close examination of teachers' actions. Through the use of both weekly quantitative surveys and a series of three qualitative individual interviews at the end of spring, summer, and fall we developed a rich description of their learning processes and activities. This close examination provided data on individual teacher learning actions, identified those actions by mode, and examined teachers' use of these learning modes through one calendar year. This manuscript contributes to bridging the theoretical understandings outlined in manuscript one and the theoretical and conceptual knowledge from the literature base put forward in manuscript two and develops practical applications for teacher learning of technology integration through a mixed-methods study utilizing teacher voice and an explanatory sequential design (Creswell & Plano Clark, 2011).

Overall Findings

As described, this line of research conducted over four years represents an evolution of our understanding of how science teachers engage in learning about technology integration and a movement from a broad focus of the topic to a more tightly focused study both in terms of subject matter and research methodology. Across these years several characteristics about (1) the nature of teacher learning in this area, (2) the organizationally implemented processes, and (3) research in this area have been identified in our studies. As well, by considering teacher learning in this area more holistically we

have been able to develop practical suggestions that may help guide school leaders in developing more effective teacher learning systems.

First, we found that the teachers in our studies engaged in a myriad of learning activities that take place outside the confines of the formal PD provided by their school districts. Often these activities are pursued so as to fill in the gaps that exist in formal PD activities. For example, we found that teachers in our studies desired on-going and just-in-time support for implementing new technologies into their instruction. This was often supported through informal interactions with their peers. These informal interactions also allowed the teachers to customize technology use for their specific student demographics or content areas and allowed them to discuss technology use in an authentic environment. The learning occurred in the context of their work as opposed to a separate activity they engaged in outside of their work. These teachers also frequently engaged in independent learning activities. They often did so to figure out for themselves how to utilize technologies that were adopted by their school divisions without provisioning adequate training. These teachers utilized their own background experiences and independent learning activities to develop technology rich instruction and valued being able to utilize their creativity in this process. These informal and independent learning activities occurred despite a lack of support from their school districts and often these teachers engaged in these activities outside of work time. Most teachers in our studies still valued formal PD activities provided to them for certain initiatives, but reported several weaknesses of these activities in terms of relevance, customization, and on-going support.

A second over-arching finding was that the school districts in which the teachers in our studies were situated primarily depended on formal PD activities for science

teacher training on integrating technology into instruction. Technology resource teachers were often employed as additional supports for content area teachers, and while most teachers in our studies valued this support, many reported it was often difficult to schedule time with these individuals or to align training time with when the training was needed. Some schools had tried to improve on-going support and teacher collaboration in this area by developing PLCs. Several teachers reported this practice as beneficial in that it provided them with time during the workday to work with peers, but also reported additional paperwork and scheduling difficulties as constraints of this practice. One school was beginning to consider and implement supports for informal and independent learning activities, and while teachers in this school reported valuing these learning opportunities they were only implemented on a small scale for a single initiative.

The third over-arching finding was that most research about how science teachers learn to integrate technology typically focuses on just a single mode of learning. Formal modes are most typically studied, followed by far less research on informal modes and almost no research on independent modes. Research is beginning to emerge on hybrid models that combine formal and informal modes. Despite this lack of research, teachers in our studies reported engaging in informal and independent activities often as part of their culture. They performed independent research and utilized what they learned, typically without considering these processes as part of an overall system for learning. These activities were often done out of necessity, and while few independent activities were reported on the quantitative surveys in our final study, all teachers in this study reported this mode of learning occurring almost daily in the qualitative interviews.

Overall, by considering science teacher learning about technology integration more holistically, we were able to better understand the interdependent nature of formal, informal, and independent modes and identify ways in which these three modes might work together. We gained insight into the affordances and constraints of each mode, and how by utilizing the affordances of one, the constraints of the others may be minimized. For example, formal learning activities can be effective in disseminating knowledge to a wide audience about district-adopted initiatives. However, on-going and just-in-time support for these initiatives are often not well supported through formal modes and informal modes of learning, such as the informal collaborations among teachers can serve to fill this gap. As well, by supporting all three learning modes, school districts may also reap additional benefits such as better dissemination of knowledge throughout their divisions and utilization of teacher experience and learning.

Further Research

Further research is required on both informal and independent modes of teacher learning. While there exists a large body of research on formal PD for assisting science teachers with technology integration, there are few studies that examine these other two modes of learning, which our research suggests teachers engage in frequently. This emerging area of research in teacher learning should be further examined to explore how to best support these modes of learning and to identify best practices for organizations wishing to facilitate these types of learning environments.

The growth and increased adoption of social media provides teachers with access to people and resources previously unavailable. This new virtual environment has the potential to greatly improve independent and informal teacher learning, but research on

how to best utilize these new tools is needed. School districts will need to update their current policies and procedures to formally recognize teacher learning through these channels and to better understand how to promote and support this type of teacher learning. As well, school leaders should consider how these learning activities could benefit the organization beyond individual teacher learning.

Finally, operationalizing a holistic teacher learning system like CANLEAD that has been the context for this line of research is a non-trivial task. While our research in this area allowed us to illustrate some best-case examples, further research on implementing this type of system will help bridge theory with practice. We heard teachers describe how they currently utilize all three modes of learning *despite* organizational support, but we are just beginning to see what their learning processes look like *with* organizational support. We envision constraints in one mode being minimized by affordances in the others, however without an example of this type of system it is difficult to move beyond theory. The CANLEAD environment is being developed to support all three modes of teacher learning and shows promise to provide us with a preliminary glimpse into this type of holistic teacher learning system.

Conclusion

As this line of research continues, it will continue to inform future development and implementations of the CANLEAD environment. The evolution of the CANLEAD materials will likewise assist in continuing this line of research and provide a unique opportunity to subsequently examine the effects of a holistic teacher learning system on science teachers' ability to effectively integrate technology into their instruction. This research represents a new paradigm in thinking about teacher learning for technology

integration and future research should start to bridge theory with practice so as to provide school leaders with conceptual and practical knowledge that will assist them in developing effective learning environments for their teachers.

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Teacher Learning Activities: The Roles of Formal, Informal, and Independent Learning

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Abstract

A qualitative study of math and science teachers at two middle schools in the same district identifies how their system for learning to integrate technology into their teaching goes beyond what school leaders typically consider when planning for teachers' learning. In addition to (a) the district-initiated, or formal, system of professional development (PD) and professional learning communities (PLCs), it includes (b) teacher-initiated, or informal, learning with colleagues as well as (c) teachers' independent learning activities. By only supporting the formal PD activities and PLCs, the district not only loses the valuable collective knowledge of the districts' teachers derived from their informal and independent learning activities, but also diminishes the learning teachers derive from the formal PD activities, as informal collaborations and independent work after formal PD activities often helps to bring the learning from the training room to the classroom. This paper provides teachers' insights that could be useful for the design of a holistic approach to facilitate teachers' formal, informal, and independent learning that is tied together and supported by technology. While research on formal, informal and independent teacher learning exists, with technology frequently mentioned as a potential support for each of these three modes, these approaches have not been considered together as interdependent parts of the same holistic system for teacher learning nor has the way technology might knit these modes of teacher learning together been imagined as a part of that system.

Teacher Learning Activities: The Roles of Formal, Informal, and Independent Learning

It is widely recognized that K-12 teacher professional development (PD) is a critical component of improving the quality of education in the United States (Lawless & Pellegrino, 2007; Birman, Desimone, Porter & Garet, 2000). It is a component that is often utilized to help teachers remain current with changes in statewide student performance standards and new methods of teaching in content areas, as well as for disseminating new teaching strategies as school environments shift and student populations become more diverse (Lawless & Pellegrino, 2007). In addition, rapidly developing areas, such as digital technology, add additional pressure on teacher PD to assist teachers in preparing their students for a more technologically sophisticated society and workplace. To accomplish this, teachers need opportunities to learn to teach in ways that differ from how they were taught and provide a technology rich environment for today's technology savvy students.

Researchers have examined teacher PD from various perspectives. Lawless and Pellegrino (2007) articulated a systematic evaluation plan for teacher PD activities in integrating technology into teaching and learning designed to help improve the outcomes of these activities. Similarily, Garet, Porter, Desimone, Birman and Yoon (2001) compared effects of characteristics of PD on teachers' learning, and identified three core features that significantly improve teachers' self-reported increases in knowledge and skills in classroom practice: (a) focus on content knowledge; (b) opportunities for active learning; and (c) coherence with other learning activities. However, while some PD has been shown to produce positive teacher and student outcomes when done effectively

(Martin et al, 2010), it is still regarded as typically inadequate in meeting teachers' learning needs (Lawless & Pellegrino, 2007).

Easton (2008) suggests the paradigm of PD be reconsidered, and instead of teacher *development* being examined, the focus be applied to teacher *learning*. The movement in schools to establish professional learning communities (PLCs), where teacher learning can be facilitated through on-going discussion groups, represents one dimension of this trend (Hamos et al., 2009). This study extends this view of teacher learning by contextually examining the role of formal structures within a holistic view of the ways in which teachers learn, including (a) formal PD and PLCs, (b) informal learning with colleagues, and (c) independent learning, to consider how teachers utilize these specific approaches and how to leverage their specific affordances.

Background

Formal Professional Development

While some specific PD programs have been shown to improve teacher knowledge and student outcomes (Martin et al, 2010), these programs rarely reach teachers on a large scale. Most teachers engage in only the minimal professional learning required of them and report these experiences as only reinforcing their existing practices (Hill, 2009). Many formal PD activities utilize face-to-face instruction delivered at specific times and inherently possess temporal and geographic related difficulties (Tytler, Symington, Malcolm, & Kirkwood, 2009; Plair, 2008). In addition to these shortcomings, PD for technology integration has additional challenges. The unprecedented growth of digital technologies and the rate at which technology now evolves create a need for greater flexibility in teacher PD. Districts struggle to identify

and develop formal PD opportunities to respond to new technological innovations. Mobile technologies and the applications that run on these devices, which typically have quick initial development times, evolve at a faster rate than traditional software designed to work on personal computers. To remain current in these technologies and understand how to effectively utilize them in instruction, teachers require learning opportunities that can evolve at a similar rate. In addition, people other than the teachers it is designed for often dictate the content and format of formal PD experiences. This system ignores teacher voice, as well as wastes opportunities to capitalize on teacher experience or build capacity within an organization (Rodrigues, Marks, & Steel, 2003). Formal PD experiences are often constrained to a specific time period and lack the on-going support teachers require (Mackey & Evans, 2011). The timing of these experiences also may not align with when teachers need the instruction.

These inadequacies of traditional formal PD models have prompted consideration of alternative formal models and how emerging technologies can be utilized. The improvements in communication technologies, specifically, have increased interest in utilizing teacher learning communities. Largely based on the theory of communities of practice (Wenger, 1998), educational organizations began developing PLCs. Communities of practice are defined as informal communities that people form as they pursue shared enterprises (Wenger, 1998). While Wenger suggests these communities cannot be developed by an organization, he believes organizations can provide supports that facilitate the development of such communities.

Recent literature focusing on utilizing PLCs for teacher learning suggest that formal PLCs (i.e. organized by the school with expectations for participation) can

facilitate improved communication among teachers, and between teachers and others, by providing structured time for sharing and collaboration (DuFour, 2004; Duran, Brunvard, & Fossum, 2009; Gerard, Bowyer, & Linn, 2010; Loving, Schroeder, Kang, Shimek, & Herbert, 2007). The benefits of this improvement include promoting a culture of collaboration and facilitating authentic and research based learning (DuFour, 2004; Lai, Pratt, Anderson, & Stigter, 2006), as well as providing access for teachers to peers, mentors, and university faculty (Loving et al., 2007). However, while formal PLCs can offer these benefits, this model of PD still exhibits shortcomings (Marsick & Watkins, 1990). For example, content and learning processes are dictated by the organization which, while serving organizational goals, may not align with teacher learning goals or preferred learning processes (Rodrigues, Marks, & Steel, 2003). As well, while improvements in communication technologies allow for virtual asynchronous communications to help alleviate the time constraints for teachers to participate in PLCs, teachers require training in this method and the tools required for participation (Loving et al., 2007).

Informal Teacher Learning

In a 2004 study by Stevenson, teachers in grades three through six in two elementary schools reported valuing informal collaboration over organizationally planned activities for learning about technology integration. In this study, the goal of the collaborations was to improve technology use in teachers' classrooms; the technologies under examination were only identified as specifically as computer hardware and software, as well as the Internet. Teachers in the study identified immediate support, new idea generation, and brainstorming opportunities as key components of informal

collaboration. This is underscored by a 2008 survey of a representative sample of U.S. schools in which various roles (technology staff, administrators, teachers, library media specialists, etc.) were ranked by the amount of support they provide to teachers integrating technology, with fellow teachers being reported as providing the highest percentage of "moderate" and "major" assistance (Gray, Thomas, & Lewis, 2010). The study by Stevenson also provided insight into the nature of informal collaborations between teachers regarding technology use. First, teachers in the study reported informal collaboration regarding technology being a pervasive part of their professional lives. The pervasive nature of these informal collaborations provide several elements of effective professional development such as coherence with other learning activities, and collective participation from teachers in the same school grade or subject (Garet et al., 2001). Second, informal collaboration among teachers is influenced primarily by time and the perceived potential for receiving information specific to their needs. The influence of time was also echoed in a case study of the online *Continuing Professional Development for Teachers* (e-CPDeIT) project, in which teachers reported the lack of provided work-time as a primary barrier to their participation in the activities (Ming, Wah, Azman, Yean, & Sim, 2010). Informal learning activities, not being organizationally sponsored, seldom receive the organizationally provided learning time provided to formal learning activities. Lastly, teachers in the Stevenson study reported seeking out two different types of individuals depending upon the broad areas with which they needed assistance; teaching colleagues for curriculum ideas and technology specialist for how-to information. This finding was echoed in a study by Tytler et al. (2009) in which teachers

reported utilizing mentoring relationships outside of the formalized mentoring program in their schools.

Informal communities of practice (COPs) we define as a group of practitioners who choose to come together to share information and work together on a problem of practice; it is because of their choice to assemble, rather than that they are organized by their school or district leaders, we consider them informal learning activities. Informal COPs share many of the same affordances as formal PLCs, such as improved communication among teachers; however informal COPs also provide a greater level of just-in-time support as well as consideration of teacher choice in content and process. Teacher support through informal COPs is not constrained by pre-set times or organizational assignments and boundaries like that which is experienced through workshop-style PD activities or through the use of an organizational technology specialist. These informal communities are often formed between teachers who are in close contact with one another, either virtually or physically, thereby improving response time to needed support. These communities are self-sustaining and allow the learners to dictate both what is learned and how the learning occurs. However, while informal COPs may allow for improved teacher choice of content and process, these choices may not align with organizational learning goals. Peer learning in these environments can facilitate teacher collaboration, but the effectiveness of these environments is also largely dependent on the participants' knowledge and skills, as well as their interactions (Riverin & Stacey, 2008). The flexibility and choice inherent in informal learning in COPs may assist teachers in collaborating with peers on specific needs and at the most convenient times. However, because of the very nature of informal learning, teachers do not receive

organizational support to participate in these types of activities and therefore must find their own time to do so outside of the work day and likely must learn to use any pertinent learning tools on their own (Ming et al, 2010). The abundance of digital resources available for informal learning such as teacher chat rooms, lesson portals, and web sites developed for teacher learning also introduces the problem of information overload (Riverin & Stacey, 2008), and without proper instruction on the use of informal learning tools, teachers may experience difficulty in effectively participating in this mode of learning. The affordances and constraints of utilizing informal COPs for teacher learning illustrate the difficulty in developing and supporting this mode of learning (Wenger, 1998), and organizations must balance the designed and emergent aspects of this type of community learning (Barab, Makinster & Scheckler, 2003).

Independent Teacher Learning

There is little research available on independent teacher learning, which we define as learning activities that teachers engage in on their own initiative and accord, and which possess no connection to their organization. However, with the emergence of social media in the last few years and the increased participation on social media sites like Twitter, FaceBook and YouTube, there is increased interest in personal learning networks (PLNs). PLNs are developed by teachers through their participation in professional learning sites, blogs, Twitter, wikis, podcasts, social bookmarking sites and online video sharing sites (Richardson & Mancabelli, 2011). This type of community learning differentiates itself from previously mentioned models such as informal COPs and formal PLCs in that the platforms used have no connection to a participant's organization, and not only is the participant's activity voluntary, it is often anonymous because of the use

of alternate logins or user names. Participation in these networks is often described through the lens of connectivism (Siemens, 2005) more so than the communities of practice framework (Wenger, 1998). While the theory of communities of practice describes informal participation in a community, which is also appropriate for PLNs, connectivism considers the impact of modern technology on how communication is facilitated and how we learn. Connectivism also reconciles the dual nature of independent learning and learning through communities. Siemens (2005) describes connectivism as such:

> The starting point of connectivism is the individual. Personal knowledge is comprised of a network, which feeds into organizations and institutions, which in turn feed back into the network, and then continue to provide learning to individuals. This cycle of knowledge development (personal to network to organization) allows learners to remain current in their field through the connections they have formed (para. 25).

This theory of learning is also appropriate as we consider learning about the subject of technology integration in instruction, which is extremely dynamic, and presents additional challenges for members of organizations who are required to remain current in this field.

PLNs may provide quicker access to information on emerging technologies, as there is no wait time for learning activities to be developed. Some teachers globally utilize social media to report, in real time, their successes and failures using new tools. PLNs possess many of the same affordances as PLCs and informal COPs, however generally utilize a larger network of resources, possess more current information on technology integration, and allow for anonymous participation (Alderton, Brunsell, & Bariexca, 2011; Hur & Brush, 2009; Siemens, 2005). Anonymous participation in these networks has been reported by teachers as allowing them the ability to discuss issues they

feel are inappropriate for organizationally sponsored platforms, and allows them to seek support without feeling intimidated (Hur & Brush, 2009). However, PLNs suffer some of the same constraints as informal learning communities such as lack of organizational support and misalignment of the teacher's and the organization's learning goals. In addition, PLNs also require teachers to possess somewhat advanced knowledge of technology in order to utilize and navigate among several different platforms (Flanigan, 2011).

Summary

Thus, we see that (a) district-initiated, or formal, systems of PD and PLCs, (b) teacher-initiated, or informal, learning with colleagues, and (c) teachers' independent learning activities each possess affordances and constraints. Each learning mode typically occurs through different configurations of uses of time and space, but all could be supported or enhanced by technological means. Although sparse, there is literature that examines how by combining modes of teacher learning their relative constraints can be overcome and new affordances can emerge.

Higgins and Spitulnik (2008), in reviewing empirical research and synthesizing the effective elements of professional development programs that support science teacher learning about technology integration, suggest that formal and informal interactions with colleagues and researchers can be effective in helping teachers integrate technology. As well, Mackey and Evans (2011) suggest that formal learning activities may be effectively supported in informal COPs through on-going and just-in-time support. Additionally, alignment of teacher and organizational learning goals may be improved through the use of informal and formal learning activities. This was illustrated in a study by Vavasseur

and Macgregor (2008) in which school principals participated with their teachers in an informal COP designed to facilitate discourse around a formal learning activity. Teachers in the study reported the principals' participation as pivotal to their success in the program, and the researchers noted that utilizing teacher and principal voice was a key aspect to the success of the program as a whole.

This study extends this emergent literature of how different modes of learning might be employed for greater effect by providing teachers' insights into how to combine formal, informal, and independent modes of learning so they flow together and particularly when supported by technology create a more holistic approach for teacher learning.

Methods

Subjects

The school district in which these case studies are set is one of the 100 largest in the country, and serves almost 60,000 students. We selected this district because of its model for providing technology integration support. The district employs technology integrators, who are certified teachers who specialize in assisting classroom teachers with technology integration. While this type of resource teacher is not unique, this district organizes these teachers by subject area. This provides, for each content area, a full-time resource teacher to assist all the teachers in that content area in the district. This model recognizes the unique relationship between content and technology and seeks to provide specialized technology support in various content areas. Technology integrators in this district have previous experience in the content area in which they work.

There are twelve middle schools in the district. Two middle schools, both serving sixth, seventh, and eighth grades were identified by district technology leaders as strong technology schools, and were recommended to us as our study locations. This purposeful sampling was used to ensure a sufficient level of data on technology integration. The schools differed significantly in student demographics, as is shown in Table 1, with one school having 18 percent minority compared with the other having 46.4 percent minority.

All math and science teachers participated in grade level focus groups; these data are the primary source of information for the study. Thompson Middle School employed 15 math teachers, and seven science teachers. Smith Middle School employed 12 math teachers, five science teachers, and two who taught both content areas. Teachers ranged in experience levels from first year teachers to over 30 years of experience.

Procedures

Six focus group interviews were conducted in total, one for each grade level in each school. Each focus group lasted approximately 60 minutes, and all were conducted during the same spring semester. The semi-structured interviews were designed to facilitate conversation among the participants through initial prompting questions. Primary questions concerned sources of information for learning about technology integration, supports required for learning about technology integration, processes for sharing technology integration ideas and knowledge, and elements which facilitate or constrain learning in this area. For each question, further probing questions were introduced to elicit additional information in areas such as in and out of school activities, online and face-to-face learning activities, and recommendations for change in

organizationally supported PD activities for technology integration. All focus group interviews were recorded, with the permission of the study participants, and transcribed.

Tools

The focus group transcripts were analyzed using a structured coding scheme made up of five primary coding areas and one supporting coding area. The coding areas were as follows:

1. Work and role of technology integrator
2. Technology use to support math and science teaching
3. Opportunities to learn, generate ideas, and sharing
4. District and school-level context
5. School and district leadership for technology
6. Analytic codes (these codes are used in conjunction with other codes to allow for another level of analysis. In this study the two analytic codes were "facilitators" and "inhibitors", which allowed us to identify factors facilitating and inhibiting technology integration within other areas.)

Data Analysis

The findings presented in this paper are based on the focus groups that generated data we coded with area number three: opportunities to learn, generate ideas, and sharing. Within this coding area, we identified three sub-codes from a review of the literature reflecting (a) district-initiated, or formal, systems of PD and PLCs; (b) teacher-initiated, or informal, learning with colleagues; and (c) teachers' independent learning activities. We categorized the ways in which teachers learned how to integrate technology into their instruction using a sub-code for each mode: formal, informal, and independent.

We operationally define and coded as formal any activities provided by the district or school, such as professional development workshops or courses, conferences, scheduled meetings with technology integrators, faculty meetings and PLC meetings. Activities were coded as informal if they were not regulated by the school or division, including informal conversations or electronic correspondence with colleagues. These informal activities often occur during planning times or before and after classes, and frequently arise from teachers being in close proximity and witnessing new teaching activities. Activities were coded as independent if they were not regulated by the school or division or did not arise from collaboration with peers; for example Internet searching, and generation of ideas based on teachers' personal experiences are included in this category. These three sub-codes were derived from our review of the literature, in which we identified these three modes of learning as distinct in their affordances and constraints for teacher learning of technology integration, but also inter-related and utilized by teachers for different types of learning activities.

After an initial review of the sub-codes and agreement was reached between the authors in terms of operational definitions, the first author coded the focus group transcripts using the NVIVO software application that allows for various lengths of text to be "tagged" by one or more codes. A report consisting of all text segments coded by specific codes and sub-codes was generated and analyzed.

Findings

Formal Professional Development

Most teachers reported general satisfaction with the formal PD activities, noting many of these activities to be beneficial in supporting their technology integration efforts,

yet also identified several shortcomings. Next, we discuss their impressions of the three primary formal PD activities that they described, which were training classes, one-on-one sessions with technology integrators, and PLC meetings, as well as the internal network for resources known as "the portal".

Several teachers recommended that training classes should be customized to content area and choice be provided as to which training classes they could attend. They felt they were required to attend classes that were not useful for them due to lack of resources or inappropriateness with their particular content area. One teacher, in discussing a summer training class, noted, "I learned a lot of different technologies, but then I came back to school and I don't have (computer carts) in my room…I saw lots of things that I could use but I don't have access to it." Several teachers also agreed that shorter classes with better on-going support would be desirable.

The scheduling of the training sessions often did not align with teachers' needs. One teacher suggested that virtual training could allow access on-demand, which would provide access to the information at the time needed. Several teachers agreed and reported scheduling conflicts as another barrier to attending training sessions. In addition to scheduling constraints, several teachers articulated that training sessions often did not provide clear alignment to their practice. One teacher indicated she would value training sessions offered by other teachers as this may allow her to see technologies authentically being used in a classroom: "I'd rather see someone else, a fellow teacher. I'd rather not have the expert come in and give me everything in three hours. I'd rather go in and watch a teacher do a lesson on it."

Scheduled sessions with technology integrators were reported as valuable in assisting teachers with incorporating new technologies into their instruction. One teacher noted, "She's just great. (The technology integrator) will take time and work with you individually, or if it's a problem that she hears from several of us, then she will do a small group kind of training." These one-on-one activities allowed teachers to suggest the content to work with, and the technology integrator would provide expertise on possible technology use. One teacher explained this process; "I was going to bring ideas to the table, they were going to bring ideas to the table, and then we'd go from there. But I was counting on them to have the expertise to move the lesson forward." Often the technology integrator would model the designed activities for the teachers by teaching the lesson in their classroom. Teachers reported participating in learning activities on how to integrate iPod touches, GPS devices and interactive whiteboards through their work with the technology integrators. There had been significant budget cuts in the school division just prior to this study, and teachers noted there were fewer technology integrators available than in the past. This greatly reduced the amount of time teachers could work with them; "If I had more access to someone like him, not having to wait so long for him to come, if I had more access for, you know, someone to be able to come once a month." Teachers were forced to schedule time with integrators months in advance and reported difficulty aligning that meeting with the teaching of the content they wanted to work on. Technology integrators also scheduled larger training sessions to provide instruction on new technologies being adopted by the district, and several teachers agreed if the new technology was one they were required or chose to use, these sessions were beneficial.

The PLC meetings provided teachers with a rare chance to sit and talk about technology integration. They expressed that these meetings were foundational in their development of effective communications with each other. One teacher noted, "I also think it facilitates rapport between teachers because you do take that time to sit down and talk to each other and that, in and of itself, can help build relationships." Several teachers reported this activity as beneficial and noted it provided work-time for teachers to discuss technology ideas around curricular content they were currently working with, allowed them to brainstorm and share ideas with their peers about technology projects, and provided them on-going peer-support for technology issues. One teacher expressed the feeling that she was missing out on important dialogue and felt "in the dark" when her schedule changed and she was not able to continue participating in her PLC. However, another teacher reported that required paperwork required for these meetings inhibited the collaboration; "It's time to do paperwork, I think. And then we share more, I think, on the fly, you know, come down and check on each other."

The school division also provided resources to teachers on their "portal", which is an internal network accessible to division personnel. Teachers reported that technology integrators assisted them in learning how to use the portal, and one teacher noted the value of this tool; "The portal for me is the best right now, just because it has the most information in one place." Most teachers agreed that the resources on the portal were valuable, but believed more could be done with this tool. They expressed the need for technology integrated lesson plans, and indicated these would provide value in their effort to integrate technology into their classes. They noted that with the number of

teachers in the division teaching the same material, this would provide a substantial benefit to a large number of teachers with minimal effort.

Overall, teachers indicated the formal PD program in the division was beneficial. Large training sessions provided by technology integrators to provide instruction for district adopted new technologies such as grading programs and interactive whiteboards, one-on-one sessions with technology integrators on the use of iPod touches and GPS devices, general discourse on technology integration during PLC meeting times, and resources provided on the internal district network were all viewed as efficient uses of resources. However, echoing findings from the literature, teachers identified temporal constraints, little customization, and the lack of on-going support as limitations of these formal activities.

Informal Learning

To overcome some of the limitations these teachers described in their formal learning opportunities, teachers utilized various informal learning activities and indicated these played an especially large support role in their use of technology for instruction. One teacher noted: "I definitely rely on co-workers. Those are the strongest supports." Another described this informal learning: "I think sometimes you just see what other people are doing. I mean you walk into their classroom and say 'oh, that's neat', and you know, get things that way." A third teacher commented, "There's a lot of sharing that goes on that's not in that meeting. I think that's the part, that like I run to (another teacher's) room and I say, 'alright, I'm really struggling with…'."

Informal learning happened primarily through email and face-to-face conversations among fellow teachers, and with teachers in others schools, administrators,

principals, library staff, district leaders and friends. Despite the popularity of social networking tools, teachers did not report using these tools for informal PD, but instead indicated using these only in non-work related activities. Teachers reported face-to-face conversations as both beneficial and efficient. They explained how short conversations in the halls—perhaps just one to two minutes in length—allowed them to get information quickly and just when they needed it; " …in between classes, at the end of the day, I use this, here you go… I mean there is some formal aspect to it but its like (teacher 1) finding ideas from (teacher 2) over a 60 second conversation."

Several teachers acknowledged formal PD activities were often the genesis of these informal learning activities. Formal and informal modes of learning appeared to be complimentary as formal PD activities provided teachers with exposure and context, and the resultant informal activities filled the gaps of on-going and just-in-time support.

Teachers noted structural, socio-human and cultural elements that supported informal learning among colleagues. One teacher described the uniqueness of her school culture, and how it promoted informal collaboration.

> We just like each other and respect each other. I have been in an environment before where you didn't ask, [which] was more because you were supposed to know everything. I mean, that's the way people made you feel. So you shouldn't come ask anything. But I think we're all very comfortable here, we respect each other, we know how each other are as professionals.

Teachers agreed that by aligning planning periods within content areas, informal interactions between teachers of the same content area were facilitated, which in turn promoted informal collaborations. One teacher described these informal collaborations: "We share lessons, we share tests, we share ideas, we share data on all of our tests, all of our quizzes. We collaborate on everything, I think probably better than any department."

Teachers in this study reported informal learning as a key component of their learning of technology integration, and one they highly valued. They noted that efficient use of time and just-in-time support were two primary benefits of this type of learning activity. They acknowledged the synergistic relationship between formal and informal activities, but also noted the importance of a collaborative school culture in promoting this mode of learning.

Independent Learning

Teachers reported participating in independent learning activities such as using Google, Brain Pop and other teacher specific web sites, such as Teacher Tube, to search for lessons and resources. Teachers frequently mentioned using the Google search engine to locate resources and lesson plans: "I think the biggest support is Google because you can Google everything and anything." Another teacher echoed this sentiment: "Biggest support? well I guess just the Internet in general, or Google, that helps me a lot." One teacher also reported utilizing professional organization web sites and private company sites as well: "Like the NSTA, Science Teachers Association, have an email list that you can join per subject area, so that's another way that I get information. And Promethean has a Promethean Planet (web site)." Now that web site creation is simple enough for people other than professional developers, teachers often use other teachers' web sites for resources and lesson plans. One teacher described this process.

> I have favorite places that I go and a lot of times they are specific teacher's (web sites). [An outside teacher] has an excellent work, she works much like I do, she has her own little website, I think it's for her students but at the bottom she says, you know, you're welcome...I never take what they do verbatim, I always have to tweak it but if they give me the skeleton, I'm not a reinvent the wheel kind of gal to be quite honest.

Video sharing sites also provide a great resource for teachers and by aggregating videos by content area and grade level assist teachers in efficiently locating resources. One teacher reported, “YouTube and Teacher Tube actually have some valuable resources, you just have to look at all of them first”, and then further articulated, “Some of them are just silly and pointless but there are a few out there that you can find that are really good.”

Several teachers indicated the importance of learning on their own and using their own creativity, and noted that with additional support they would be more inclined to implement lessons conceived in this way. One teacher commented, “I guess that does make us rely on our own creativity more and more, and I like that. The fact that we put so much time into thinking ‘what would the kids actually like and get out of it?’” This teacher then described this process further as “that's what real teaching is about.” Several teachers also report that there are times when adequate support is not provided and they choose to employ independent learning: “I found that I’ve done a lot on my own to learn some of the tools that we need or that we use in science.” Another teacher noted that learning new technology tools often requires more than a single training session, and that she requires time to play with the tools on her own: “We have some sessions on it but you can't really learn until you get in and start to use it, I think. That's me as a learner; I have to do it in order to learn it.”

Several teachers communicated the desire for training in how to better utilize web resources for independent research as well as for time to be built into their schedule for this type of research. One teacher articulated the need for organizationally provided time to learn how to integrate new technologies in her classroom.

> It comes back to the time thing… you will become more efficient with all the technologies when you have time to play with it, practice it on your own, individually. So if we're not given time during the school day I mean we will use some time at home but that's limited. We all have other things that we do at home, other people that need us and so forth. So the more time you spend with something, the more comfortable you become with it. Then yes, you're efficient and it becomes worthwhile and it becomes productive and exciting for the kids other than a piece of paper. But when we don't have the time to do that, you know, don't bring more and more technology even though it may look great on paper it's not going to be if I don't have the time to put it together, it's not going to work; it's not going to be efficient for me either.

Teachers in this study reported independent learning as another primary activity crucial to their learning of technology integration. They expressed positive feelings about being able to utilize their own knowledge and creativity in this process. However, they reported a lack of organizationally provided time to engage in this type of activity, and a desire for instruction on how to better utilize independent learning tools and techniques.

Discussion

From the viewpoint of the teachers at these schools, their system for learning about technology integration is comprised of three parts, the constraints of each generating the needs for the others: (a) the formal system of PD and PLCs provided for and arranged by their school; (b) informal learning from colleagues; and (c) independent learning. As one would expect from its very definition, the primary support for learning about technology integration that school leaders provide is this formal system. Yet the teachers' reports of the affordances and constraints of this system as compared to their informal learning via collegial networks and independent learning efforts provides insight into how, where, and why teachers want more support for learning, the limits of the system leaders provide for it, and what might be lost as a result of this gap.

Teachers reported valuing their time in PLCs as a rare chance to discuss ideas and collaborate but indicated a desire for additional provided work time during the school day and the means for collaborative efforts, underscoring the need for content specific support that is on going and just-in-time. Were access to outside expertise needed, this may also necessitate tools required to overcome geographic and temporal limits. Teachers in this study reported that informal learning, such as face-to-face and email conversations, addressed specific questions and was not constrained by pre-scheduled meeting times and places. Teachers' independent learning efforts made highly efficient use of their time and allowed them to bring their own new and creative ideas into the school as they researched specific areas of interest.

That teachers had these needs for additional means to learn beyond formal PD is not as surprising as the fact that formal PD systems continue to have such shortcomings, as documented earlier in the literature. The now decade-old work of Bransford, Brown and Cocking (2000) provides specific guidance as to effective learning environments that would foster deep teacher learning. An examination of their recommended four essential elements for effective learning environments, synthesized from relevant cognitive science research, nearly predicts these teachers' responses to go beyond formal PD offerings and generate additional means for their learning ends. The first of these recommendations is that effective learning environments should be *learner-centered,* meaning that individual learner knowledge and prior experience be taken into account, while also being *knowledge-centered,* or directed toward developing deep understanding. To foster the development of deep understanding, they should also be *assessment-centered,* using feedback and other assessment mechanisms to guide the learner. Learners also gain

guidance and feedback from a *community-centered* learning environment, which allows for the dispersal of common information and the development of norms and shared meanings.

Considering the affordances and constraints teachers identified for the formal, informal, and independent learning activities for technology integration in terms of the Bransford, Brown and Cocking four-part framework for effective learning environments provides further analytic power to why each part is needed and how the modes of learning work together. As also shown in Table 2, informal and independent learning activities also possess constraints, suggesting that rather than a replacement to formal PD, school leaders should consider how to strengthen support for informal and independent learning while integrating them with formal PD.

By only focusing on and providing support for formal PD activities, school districts limit not only individual teacher learning, but also the collective knowledge of their teacher population. An opportunity is lost to capitalize on the personal and collective efforts, as well as the diverse experiences and perspectives of teachers. The complete benefit of even the formal PD activities is never realized as informal and independent activities arising from formal activities are not supported and therefore rarely occur.

While districts are investing significant time and money into formal teacher PD, they are missing opportunities to enhance the teacher and student outcomes by not supporting the current routines and processes already in place. Teachers in this study reported informal learning as a major source of assistance in incorporating technology

into their classrooms. School districts would be remiss in not capitalizing on this process to improve and establish a more efficient program of teacher learning.

In summary, each mode of learning supports the others in powerful ways and together they illustrate the range of learning approaches teachers might choose to use and that schools may be well served to support. Formal PD activities can bring teachers together and promote further collaboration to continue through informal learning. Informal collaboration can provide the necessary on-going and just-in-time support for projects that originated in formal PD activities. Independent activities can also spawn informal collaborations, or provide the needed background knowledge and skills to support collaborations that began in formal or informal activities. Teachers in this study reported that each mode of professional learning is important, useful for different learning situations, and supportive of the other modes. Thus, we conclude that the three modes should be considered altogether as a holistic system for teacher learning, and by doing so we believe that each investment made in teacher learning would be better spent by closing gaps in the system that contribute to potential loss of learning and lack of follow-through.

Implications

In this section we discuss the implications for school leaders who seek to meaningfully provide leadership and organizational supports for each mode as a complement to the others. One key implication for leaders is the opportunity to model for teachers and give them first-hand experience with high quality learning environments. School leaders could explicitly model checking for gaps in the holistic teacher learning in terms of quality learning environments (c.f. Bransford, Brown & Cocking, 2000), and

then systematically strengthening each component part as well as the connections among them. Utilizing emerging technologies for teacher learning also serves to provide hands-on experience with technology integration into pedagogy, modeling for teachers how they could use technology with their own students. Teachers are presently in a unique position where they are asked to teach utilizing these quickly evolving technologies, a style with which they are often unfamiliar. However, by experiencing these technologies as learners they could gain valuable perspective and knowledge, and in teaching as they were taught, become prepared to utilize them for engaging, high quality instruction.

Another key implication is that district leaders should consider how altogether their leadership practices (and the tools, routines, and structures of which they are comprised), combine to facilitate a range of supports for formal, informal and independent teacher learning activities. For example, they may find their mandates for, recognition of, and policies regarding teacher PD activities need to be amended to include informal and independent learning activities in the same light as formal learning activities. It would likely soon become apparent that in order for teachers to be able to use new tools effectively that they should receive training on them, which could be most systematically addressed through tools and time provided by the organization as formal PD. Independent learning activities require time to allow teachers to discover new technologies relevant to their needs and draw upon both their experience and creativity, and informal collaboration opportunities require structures to be put in place so as to assist in subsequently disseminating teacher discoveries through the organization. These learning activities will also benefit from leadership participation as well as organizational facilitation when needed.

The third implication is that school leaders must formally recognize the presence of and contributions from each of the three learning modes. Balancing the affordances and constraints of each mode should be combined with considering how technologies might weave together the modes. For example, formal learning activities are hampered by lack of on-going and just-in-time support—two constraints that can be eased by informal learning tools such as virtual communication platforms. District leaders should specifically consider how emerging technologies could assist them in facilitating this new paradigm of teacher learning. Social media is well suited to support various aspects of formal, informal, and independent teacher learning as it powerfully connects people who are not geographically proximate. This might mean school leaders promoting the use of Facebook or Twitter and other social media for informal teacher learning activities to overcome temporal and geographic constraints, as well as to create virtual communities and access crowd-sourced data—all important for just-in-time and on-going support.

School leaders need only to look at current teacher practices in this area to envision and implement a more holistic teacher learning system. Teachers in this study reported that formal training sessions were often useful for initial exposure to new technologies. Examples were provided about training sessions for the Promethean interactive white boards, Google earth, and a district adopted online grading system. It was also noted that informal learning activities, often facilitated through emails, were effective in supporting sharing among teachers and between teachers and other support personnel. Finally, teachers noted that independent learning activities gave them the opportunity to engage in hands-on work with the technologies and the ability to infuse their experience and knowledge of their specific student demographics into the process of

curriculum development using technological tools. School leaders can aggregate and expand on these activities in several ways. For example, by providing formal learning opportunities on the use of informal learning tools such as social media, school leaders provide the training necessary for teachers to more effectively utilize these tools for their informal learning. This will also allow for future formal learning opportunities to be better supported through the addition of informal learning tools such as online discussion boards or social media sites such as Twitter with accompanying hash tags. School leaders will further incentivize teachers to engage in these types of activities by modeling effective participation using these tools, and by aggregating and sharing the knowledge generated through this medium they will be able to better disseminate knowledge throughout the organization and build capacity within the organization. In addition, school leader participation in these informal learning environments will provide them with insight into what supports teachers need and what technologies are being developed in the various content areas. By providing time during the workday for independent learning activities and training and access to informal sharing platforms, school leaders will support the important independent work teachers currently do, and allow for this work to be shared with others in the district. To develop a more holistic teacher learning system for technology integration, school leaders need only recognize what teachers currently do, remove barriers to these types of learning activities, provide supports for these activities, and continuously expand on the benefits associated with the new synergies created.

Conclusion

By considering each mode of teacher learning, school divisions should develop teacher learning activities for technology integration that consider teacher learning in a more holistic way, utilizing the affordances of formal, informal and independent learning activities for areas best served by these types of activities. The use of emerging technologies, such as social media, should be explored and utilized when a demonstrated benefit is identified. Incorporating these tools will help create a technology-rich infrastructure, provide valuable technology learning experiences for teachers, and facilitate communication necessary for informal learning activities. By using social media tools such as blogs and forums, and supporting informal collaborations, school districts can begin to establish a documented knowledge base efficiently. Just as Web 2.0 companies such as Google and YouTube have become successful by creating platforms for users to generate and navigate content, school divisions can employ the same "crowd-sourcing" methodology to capitalize on the diverse experiences and hard-work of their teachers and staff. By considering the collective whole of the system, not only might each mode be better facilitated, the system as a whole might be improved from the synergistic relationships illustrated in these data. This improvement should promote greater teacher and student outcomes, as well as more efficient use of district resources.

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Table 1

Student Demographic Information for School Sites

School Name*	**Level**	**Grades Served**	**Percent Minority** [B]
Thompson Middle School	Middle	6 – 8	18
Smith Middle School	Middle	6 - 8	46.4

Note. * School names are pseudonyms; [B] Black (not of Hispanic origin), American Indian/Alaskan Native, Asian, Hispanic, Native Hawaiian/ Pacific Island.

Table 2

Affordances (+) and Limitations (-) of Learning Modes by Aspect of Effective Learning Environment

Aspect	Formal PD	Informal PD	Independent
Learner-centered	- topics dictated by organization not by learners + Alignment of schools' and teachers' learning goals + Assurance of exposure to mandated skills	+ Allows participant choice of both content and learning process + Considers teachers' experience, and unique situations + Considers teachers' diverse talents and experiences - Lack of assurance of participation in mandated activities + Flexibility in participation time	
Knowledge-centered	- Lack of ability to address content-specific skills - Lack of on-going and just-in-time support + Organizational support for securing outside experts + Organizational support for provided time - Shorter in duration	+ allows for content-specific learning + Provides on-going and just-in-time support - Lack of expertise outside of school or division + Learning is situated in practice - Lack of organizational support for time + Continuous on-going learning - Effectiveness dependent on participants - Information overload	+ Greater reach to outside expertise - Lack of knowledge in using independent learning tools - Effectiveness dependent on participants + Greater amount and variety of resources + Quicker access to emerging technologies - Lack of organizational support for time - Lack of organizational support for training on tool use
Assessment-centered	This aspect was not evident in the data for any of the three parts, but formative feedback and or reflective activities could be a part of any of		

	them.		
Community-centered	+ Localized community learning - misalignment of scheduling with teacher need + Improved communication within school of district - No capacity building within organization	+ Additional learning time through asynchronous activities + promotes collaboration and community development + improved communication within and outside school or district - difficult to develop and sustain informal learning platforms	+ community development outside of school of district + improved communication with peers globally + advantages of anonymity

Running Head: HOLISTIC SCIENCE TEACHER LEARNING

Considering Science Teacher Learning of Technology Integration From a Holistic Perspective

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Abstract

Science teachers require effective learning experiences to successfully integrate technology into their instruction. These experiences can be facilitated through learning communities. While several varieties of learning communities exist, three models have been identified in the literature. Formal professional learning communities, informal communities of practice and personal learning networks each have unique features that facilitate formal, informal and independent modes of learning. While research on each of these modes and their respective models exists, as well as a small amount of research on combining modes, there is a gap in the literature examining how all three modes work together. This review of empirical research examines each of these modes with their associated models and illustrates how the affordances in modes counteract the constraints of the others. We conclude with the recommendation that a holistic model, incorporating all three modes, should be considered when designing technology integration learning experiences for science teachers.

Considering Science Teacher Learning of Technology Integration From a Holistic Perspective

Providing effective learning experiences for science teachers is critical to promoting effective use of technology in their classrooms (Gerard, Varma, Corliss, & Linn, 2011; Higgins & Spitulnik, 2008; Rodrigues, Marks, & Steel, 2003; Vavasseur & Macgregor, 2008). While there are numerous, and often ambiguous, terms defining varieties of learning environments, three main models have been identified in the teacher learning literature: professional learning communities (PLCs), communities of practice (COPs) and personal learning networks (PLNs), supporting formal, informal and independent modes of teacher learning, respectively. Most reviews of research surveying aspects of effective learning experiences for science teachers focus only on formal modes of teacher learning, such as through formal professional development and professional learning communities (Gerard et al., 2011; Lawless & Pelegrino, 2007).

Yet it was over 20 years ago that Wenger (1998) identified the community of practice model, thereby giving a name to informal learning among professionals that extends beyond formal learning models for how teachers might learn. More recently, the emergence of new information and communication technologies and associated affordances have nurtured independent modes of learning, such as the PLN model; these trends have increasingly directed teacher educators' and researchers' attention to how technology can support teacher learning communities and social networks (Higgins & Spitulnick, 2008).

In this review of the literature we bring together a discussion of all three modes of teacher learning (formal, informal and independent), and their three correlated models

(PLCs, COPs and PLNs). We synthesize current research on these modes and models by taking a holistic view to suggest how when woven together the affordances from each might be used to minimize the constraints of the others and altogether provide an effective environment to facilitate science teacher learning of technology integration.

Definition of Terms and Conceptual Framework

Many labels have been applied to models of teacher learning environments: professional learning communities, professional learning networks, communities of practice, teacher learning communities, online learning communities, personal learning networks, virtual communities, personal learning environments and open network learning environments. These labels can indicate subtle or substantial differences, but often simply reflect researchers' preferences. Next, we define terms for each of these different learning modes and models, drawing upon how they are typically discussed in the literature.

Formal Learning

Formal learning experiences are planned and developed by the school or organizational leaders. The experiences are highly structured and there is typically little flexibility in the learning experiences (Marsick & Watkins, 1990). This mode is best illustrated both by traditional teacher professional development activities such as workshops, and more recent models like PLCs, which emphasize longer duration professional development through periodic scheduled meetings among teachers.

Informal Learning

Informal learning experiences are predominately experiential and not initiated by the organization (Marsick & Watkins, 1990). Face-to-face, email, or social media

facilitated conversations with peers, informal collaborations between teachers, and peer support are examples of this mode of learning. There are no pre-conceived notions of a beginning and ending to these experiences, and learners decide what is learned and how. Emerging communication technologies have enabled teachers to extend their reach to greater numbers of sources of informal support and collaboration. These virtual communities provide improved access to peers and allow for new collaborative efforts between higher education faculty, content experts and teachers (Barab, Makinster, & Scheckler, 2003). These informal communities are often developed for research projects (Rodrigues et al., 2003), and provide much of the literature base on informal modes of learning. When teachers work together in these ways we refer to this model as an informal COP.

Independent Learning

In addition to formal and informal modes of teacher learning, independent learning has been identified in both the literature for teacher learning as well as for workplace learning, there termed incidental learning, as a third mode of learning that individuals engage in within organizations (Jones & Dexter, 2012; Marsick & Watkins, 1990). Independent learning experiences, while sharing traits with informal learning experiences, distinguish themselves as developing through independent, sometimes unintentional, learning activities (Marsick & Watkins, 1990). Participation in self-generated online communities (Hur & Brush, 2009), independent participation in social media (Alderton, Brunsell, & Bariexca, 2011), and use of personal experiences are forms of independent learning experiences, which in various combinations forms what we refer to as the PLN model.

Emerging technologies, specifically social media, allow teachers to develop PLNs. Social media web sites such as Twitter, FaceBook and YouTube allow teachers to share and reflect on resources, videos and ideas (Beach, 2012). These social media sites provide tools, such as hash tags, that allow teachers to develop their individual network, find information quickly, and utilize others' expertise in vetting resources and lesson plans (Dobler, 2012).

Conceptual Framework

Despite the difference in terms and subtle facets of each model, the theory of situated learning and legitimate peripheral participation in communities of practice (Lave & Wenger, 1991) is often cited as a core design tenet for many of these models. Teachers engage in a variety of different learning communities and their levels of participation and style of engagement may vary according to the norms of each community. Teachers may participate as primary agents in their departments or schools, or peripheral participants in larger virtual teacher communities. These communities may be situated in their work environments or exist on a global platform. This theory recognizes the unique characteristics of each of these types of communities of practice, as well as how participation in one type of community can affect participation in others. Wenger (1998) defined communities of practice as the informal communities that people form as they pursue shared enterprises, thus making this theory an appropriate lens to consider the model of informal COPs. Further, this theory also recognizes the social character of learning, a core assumption that engagement in social practice is the fundamental process by which we learn as opposed to the view that learning is the reception of factual knowledge. This theory is also an organizing idea behind forming

PLCs for formal learning and an organizing assumption of the value of PLNs. Here, we draw on this theory to provide an analytic lens for examining how teachers engage in the process of learning how to integrate technology into their instruction by highlighting in each model of learning its agents, activities, communications, development, and tools of its community of practice.

Selection Criteria for Research to Review

Considering science teacher learning of technology integration, we sought out empirical studies of formal, informal, and independent modes of learning though teacher communities, as well as hybrid models that combine modes. We did not attempt to comprehensively examine all aspects of science teacher learning of technology integration (see instead Gerard et al., 2011 and Higgins & Spitulnik, 2008), but instead gathered here explicit examples of empirical studies of each of these three modes and their associated models to gain insight into how each might offer particular affordances or constraints for science teacher learning for technology integration.

This review of empirical literature addresses gaps in the literature by considering all three modes of learning in the same review, thereby taking a science teacher's perspective for looking at the possible menu of options for learning to integrate technology and allowing a discussion of the relative merits of each mode as well as the relationships among their affordances and constraints. In addition, by focusing on just those studies that incorporate some form of community-based learning for teachers and including the independent mode of learning and PLNs, we explicitly consider the changing landscape of teacher learning that is afforded by the emergence of social media and other Web 2.0 tools. Thus, we consider how these three modes and associated

models can be applied holistically, leveraging technology, with a community of teachers to promote effective science teacher learning of technology integration.

Due to the variety of terms used to describe teacher learning communities, several search keywords such as *professional learning communities, personal learning networks, communities of practice, learning communities, technology integration, science teaching, and professional development* were used in a search of the following databases for peer-reviewed articles published between 2003 and 2012 using the EBSCO host web site: ERIC, Academic Search Complete, Education Research Complete, Teacher Reference Center, Psychology and Behavioral Sciences Collection. As well, we conducted legacy searches, hand searches of recent journals, and searches of specific journal web sites. To provide broader context, Google scholar was searched with related terms, authors' personal web sites were searched, and in one case an author (i.e., Mackey, 2010) was contacted via email to acquire the full dissertation on which a research article was based.

While we attempted to locate empirical research focused just on science teacher learning of technology integration using teacher communities, the paucity of research in this area dictated expanding our search outside of the science content area to examine use of modes and models that could inform practice in science. Each of the eleven studies identified in this review focus, in part at least, on teacher learning of technology integration, and all incorporate in-service or pre-service teachers responsible for science instruction. The chosen empirical research illustrates the use of learning communities for formal modes and PLCs (Duran, Brunvard, & Fossum, 2009; Gerard, Bowyer, & Linn, 2010; Loving, Schroeder, Kang, Shimek, & Herbert, 2007), informal modes and informal COPs (Ming, Wah, Azman, Yean, & Sim, 2010; Riverin & Stacey, 2008; Rodrigues et

al., 2003; Stevenson, 2004), independent modes and PLNs (Alderton et al., 2011; Hur & Brush, 2009) and combined models (Mackey & Evans, 2011; Vavasseur & Macgregor, 2008).

Formal Learning Mode and the PLC Model

The body of literature on formal learning experiences and PLCs is emerging, however only three empirical studies (Duran et al., 2009; Gerard et al., 2010; Loving et al., 2007) were located which focused on technology integration for science instruction. These three studies offered distinct and different lenses through which to examine formal learning and PLCs in this area, and together present a well-rounded illustration of this mode and model of teacher learning. Together the studies investigated the use of PLCs by in-service teachers, mentor and supervising teachers, alternative licensure interns, first year teachers, college faculty members, student teachers, and school principals. Findings from all three studies conclude that the communication benefits of PLCs offer improved learning experiences for technology integration in science instruction.

In their longitudinal mixed-methods study of the Michigan Teachers' Technology Education Network program, Duran et al. (2009) examined the benefits of facilitating communication between student-teachers, in-service teachers, university faculty and student teaching supervisors in what they termed a *networked learning community*. Technologies explored through this program fell into three areas: telecommunication tools, productivity tools, and educational multimedia. Over the course of three years, 50 participants in five cohorts provided data through pre- and post-surveys, journal entries, participant observations and electronic portfolios that were analyzed to examine the impact of this learning community on the technology integration skills of the participants,

and particularly the effect on the pre-service teachers. Results of the first part of the study indicated that participants made significant increases in their use of technology for connectivity (i.e. sending and receiving emails with attachments, using Internet search engines), creating multimedia presentations, using graphics applications to create documents, and creating personal or professional web pages. Results of the second part of the study indicated that participants made significant improvements in assisting students with using a variety of both hardware and software applications, spent more time helping students use content specific applications, improved in helping students become skilled at developing their own technology-enriched learning activities (e.g., ePortfolios), and utilized more electronic tutorials to teach specific lessons. Participants also exhibited significant improvements in mentoring their colleagues in using technology to improve the teaching and learning process. Specific technology tools used by the participants were dependent on their grade level, and ranged from Kidpix and Kidspiration for early elementary to eChem and ChemFinder at the high school level. Utilization of PLCs, such as the one in this study, for pre-service teacher learning presents a new strategy compared to many traditional pre-service teacher preparation programs in which a single technology integration course is offered. By utilizing a diverse learning community, Duran et al. found that pre-service teachers in this program were provided with networking opportunities, mutual learning experiences, and an environment for sharing of strategies and resources that provided an effective technology integration learning experience.

As pre-service science teachers enter the field, the improvements in communication offered by PLCs may continue to play an important role in their

professional development. Loving et al. (2007), in a study of the Professional Learning Community Model for Alternative Pathways in Teaching Science and Mathematics, reported that availability of distributed expertise in a PLC helped support high quality science content and learning theory. This five-year mixed methods case study focused on the use of asynchronous communication supported through a blog between 15 intern teachers, 11 mentor teachers, college professors, education researchers and scientists. Survey data indicated significant improvements in participants' confidence of (a) developing instructional units requiring students to use the Internet, (b) using email, discussion lists or chat rooms to improve understanding of technology and teaching, and (c) using technology to reflect on teaching practices. Participants utilized the blogging platform to share web resources, and some indicated the desire to use a similar platform with their students, as well as continue to use a blogging platform to reflect on teaching practices. Researchers concluded that the virtual PLC facilitated asynchronous communication and indirectly benefited most of the participants in terms of integrating technology into their teaching practice, which we note as a promising finding considering the temporal and geographic constraints that teachers often cite as barriers to collaborative work.

School leadership can also play a central role in helping teachers implement technology-enhanced science instruction. In a case study by Gerard et al. (2010) seven principals from different schools in the same division were brought together to collaboratively develop leadership practices to support a new technology-enhanced science curriculum. Gerard et al. suggest this PLC of principals had positive effects on the implementation of the new curriculum. The schools in this study had each agreed to

supplement their science curriculum with modules from the Web-Based Inquiry Science Environment (WISE; see http://www.wise.berkeley.edu). The WISE modules utilize interactive models, graphs and simulations to assist with instruction of abstract scientific concepts. Principals assisted each other in the PLC through conversations about the challenges of reform and strategies that might be effective, and throughout the three-year project demonstrated improved ability in collaborative learning. The experience in the PLC also translated into more active principal leadership in their schools in support of science teachers' curriculum reform efforts. Through analysis of principal community meeting transcripts, interview data with each of the principals, observation and attendance reports from each principal community meeting and questionnaires, the researchers concluded that conversational exchange in the PLC stimulated instructional leadership for the technology-enhanced science curriculum reform. The principals reported their experiences in the PLC had positive implications for their interactions with their science teachers as they translated aspects of their PLC experience to their working relationships with their science teachers. Through this translation process, principals reported a culture of learning from colleagues was developed, and they initiated powerful conversations between themselves and their teachers. This cultural shift allowed for teacher perspective to be utilized, improved principal participation and knowledge, and created alignment of school goals with teacher learning priorities.

By systematically examining the agents, activities, communications, development and tools of the PLCs described in these studies, we can identify the affordances and constraints of this model for science teacher learning of technology integration. While these study designs do not allow for causal or even correlational conclusions, nor make

these results generalizable, their longitudinal designs and mixed methods do make them rich descriptions of instances where improvements in communication stemming from PLCs employed to support science teacher learning suggest positive implications for pre-service teacher preparation, in-service teacher learning, and educational reform projects.

In each study, the organization is the primary agent for development and facilitation of the learning community. This structure advances organizational learning goals effectively and provides organizational support for learning activities, suggesting PLCs may be effective for teacher learning of district-wide initiatives. However, people other than the participants for whom the learning experience is designed dictate topics and content, and this typically leaves little room for teacher voice and experience to inform the learning activities. As well, while this structure promotes local collaboration, it limits participation in the community to the organization's population. Learning activities in the PLCs in each of these studies illustrate improved communication among teachers, between teachers and principals, among principals, and between teachers and outside collaborators (e.g., University faculty, scientists, mentors, outside experts). However, communication in PLCs is often facilitated through the use of technological tools, which while providing access to a larger and more diverse group of people than previously possible, also introduces the constraint of a minimum level of technological competence (Loving et al., 2007).

Informal Learning Mode and the Informal COP Model

The literature base of empirical research in this area is sparse. By expanding our criteria to examine teacher learning communities not solely focused on science, we were able to identify four empirical studies with which to describe this mode of learning and

inform our analysis of its possible use for science teacher learning of technology integration. One study focused on science teacher learning of technology integration (Rodrigues et al., 2003) and another examined science, English and mathematics teachers' learning of technology integration (Ming et al., 2010). The two remaining empirical studies examine teachers' participation in informal modes of learning and illustrate important aspects of this mode of learning. The first describes informal elementary teacher learning for technology integration (Stevenson, 2004), and the second examines teacher participation in an informal national community during a ten year period (Riverin & Stacey, 2008).

While the informal communities examined in the following studies have similarities to formal PLCs, the differentiating aspect of informal COPs is the intent that the communities will be self-supporting and not facilitated by an organization. In the following studies, learning in the communities being examined was facilitated through collaboration and internal expertise (Ming et al., 2010). Many of the affordances attributed to formal PLCs can also be attributed to informal COPs, such as improved communication among teachers, but informal COPs can offer teachers choice in their learning content and processes, a greater level of just-in-time and on-going support, and a sharper focus on collaboration.

Informal teacher learning communities cannot, by definition, be facilitated by an organization. However, as Rodrigues et al. (2003) illustrate, organizations can minimize the barriers to informal learning. In their study of the Partnership in Primary Science (PIPS) project, they created a cross-school informal community of practice with the intent of promoting teacher ownership of the community and allowing teachers choice

over the activities and the processes through which learning occurred. The intent of the continuing professional development activities was to assist science teachers in utilizing information and communication technology (ICT) in their teaching as well as to refresh their understanding of science concepts. The researchers described the design of the PIPS project:

> The PIPS model encouraged the development of communities of practice to support teachers to adopt informed positions on pedagogical issues related to the use of ICT in terms of curriculum and assessment and hence influence their classroom practice. This model also requires community development of educational practices that take on board pedagogical issues and "know how". (p. 388)

One of the primary assumptions in developing this model was "changes in pedagogical content knowledge must start from the teachers' perspectives and requires teacher ownership of the change process" (p. 388). This assumption illustrates the conceptual difference between most forms of formal and informal teacher community learning activities. The researchers further articulate the differences in formal and informal modes of learning by contrasting the over-centralized and didactic nature of traditional formal teacher learning activities to the PIPS model, where the participants control both the content and learning processes. Teachers in this study reported greater confidence in using tools such as data loggers, Powerpoint presentation software, and Palm handheld devices. They also indicated that learning about these technologies in the context of science instruction provided a more valuable learning experience than learning about the technologies as stand-alone tools. The researchers of this study suggest this allows for the teacher learning experiences to account for the composition of the community as well as the practice intended, which in turn allows for teachers to learn about technology integration in science in an "informed and appropriate way" (p. 393).

Despite the benefits of informal COPs for teacher learning, sustaining an effective community of this type is difficult, and successful participant adoption of these communities has several barriers. In their case study of the online Continuing Professional Development for Teachers (e-CPDeIT) project, Ming et al. (2010) examined twenty teachers' use of this online platform and identified several challenges. The online platform was designed to facilitate a self-sustaining informal COP focused on helping teachers improve their technology skills and motivating them to use these skills in their instruction, and at the end of the first year, the researchers suggested that an informal COP was not successfully established. As in the previous study, this platform was intended to allow teachers to internally develop capacity and not depend on organizational facilitation. The project sought to develop an informal "COP oriented PD that features collective participation and active learning that builds on teachers' prior knowledge" (p. 404). Teachers in the study reported time as a primary barrier, and more specifically, organizationally provided free time. Time is an often-reported barrier to all teacher learning experiences, but researchers of this study suggest time for informal learning experiences is an even greater problem due to the lack of organizationally provided free time typically allocated for formal learning activities. Teachers in this study also reported fear and lack of confidence in using technology-related platforms as additional barriers to participation, which can have important implications particularly in the area of teacher learning of technology integration. Teachers in this study used blogs to share narratives of perceived good lessons, digital video to share video of lessons, and online forums to discuss practice. While these technologies may be new to teachers and possess barriers to use, exposing teachers to these technologies as learners may increase

their efficacy in using these tools for instruction. However, while the use of technology mediated instruction can enhance teachers' ability to integrate technology into their own instruction (Riverin & Stacey, 2008), without a basic working knowledge of the tools, they may continue to be hesitant to engage in these activities. Specific applications of technology for instruction, or use of specific technological tools were not provided in the study. Researchers of this study suggest the administrative and institutional support for informal learning, as well as the proper design and required teacher training in the use of informal instructional tools are critical elements to consider in design of these types of learning activities.

To better understand the nature of informal teacher collaboration regarding technology, Stevenson (2004) conducted a case study of six elementary teachers that examined the informal communications these teachers used to learn about and implement technologies in their instruction. While these teachers reported discussing specific ideas regarding technology in the curriculum, the only specific technology mentioned in the study was digital cameras, which the school division had recently purchased. Using questionnaires, individual interviews and focus group interviews, several assertions were suggested about the nature of informal collaborations with these teachers. First, teachers value informal collaboration as a more effective method of professional development than organizationally developed activities. Teachers in this study reported immediate support, new idea development and the ability to brainstorm with one another around curricular issues as being facilitated through informal collaboration. A second assertion is informal collaboration is a pervasive part of teachers' professional lives, not a separate activity. This pervasiveness inherent in informal teacher learning provides several

features identified in other research with effective professional development such as coherence with other learning activities, duration of activities, and collective participation of teachers from the same school, grade or subject (Garet, Porter, Desimone, Birman &Yoon, 2001). As well, the localized learning in many informal COPs may increase the likelihood that training focuses teachers on their practice, rather than pulling them away from it (Schlager & Fusco, 2003) .

While emerging communication technologies may provide teachers more informal learning opportunities through improved access to resources and other professionals, Riverin and Stacey (2008) suggest it may also magnify the issue of information overload in their study of The Education Network of Ontario. In this case study, activities of two groups of teachers who utilized the platform for ten years and four years, respectively, were examined to determine how these teachers used the skills acquired through this network. Researchers of this study suggest three important factors for success in online communities; the level of information overload, the tone of the environment, and outreach and marketing. They suggest that unlike formal learning communities that can be facilitated through an organization to maximize learning, the effectiveness of the informal communities in their study depended on the self-generated culture of the community. The two groups of participants, teachers who had joined at the onset of the project and ones who had joined later, reported differing attitudes towards feelings of community and desire to participate. The teachers who had joined earlier felt a much stronger sense of community, likely due to the smaller number of participants, and were more open to discussions and participation than the group who joined later, who reported feelings of intimidation which led to fewer postings and less overall involvement

in the community. Despite these divergent views from participants, both groups reported developing new technological skills with various tools (the specific tools were not noted in the study), online communication skills, and leadership and collaborative learning skills through their involvement in the community. Participants also noted improvements in their Internet research skills and increased confidence to experiment with new technologies in their classrooms. As well, both groups reported integrating new ideas and resources that were acquired through their interactions in the network into their teaching practice and forging new alliances with other members of the community.

By again examining the agents, activities, communications, development and tools of the informal COPs described in each study, we can identify the affordances and constraints of this model of teacher learning. COPs in each study allowed for greater participant choice in activities, however these activities may not align with organizational goals and the effectiveness of these activities may be largely dependent on the participation and attitudes of the community agents (Riverin & Stacey, 2008). Teachers played a more explicit role in shaping the learning activities and developing the relationships in the informal COPs than was evident in the formal PLCs examined in the last section. Participation in the informal COPs in each study was not dictated by an organization, and therefore teachers could choose their level of participation and their methods of communicating with others in the community. Activities in the COPs in each study offered improved flexibility in terms of time, but do not benefit from administrative support in terms of designated free-time during the work day or organizational training in the use of required technological tools (Ming et al., 2010). One study also noted the

abundance of resources now available for informal learning experiences may also contributed to the issue of information overload (Riverin & Stacey, 2008).

Independent Learning Mode and the PLN Model

The emergence and adoption of social media through sites such as Twitter and Facebook have renewed an interest in the independent teacher learning mode and the PLN model. The literature in this area is emerging, and several books have recently been published concerning the use of PLNs for teacher professional development (e.g., Nussbaum-Beach & Ritter Hall, 2012) as well as utilizing PLNs for K-12 instruction (e.g., Richardson & Mancabelli, 2011). PLN use focused on science instruction is also gaining interest as professional organizations are considering the possible affordances of this model of teacher learning (Mitchell, 2011). However, empirical research focused on using the PLN model for technology integration in science instruction could not be located. Instead, two studies investigating educators' independent use of online networks are examined here to illustrate the possible affordances and constraints of this mode and model for science teacher learning of technology integration. In the first study, Hur and Brush (2009) examined teacher participation in a self-generated online community, and in the second study, Alderton et al. (2011) examined educators' use of Twitter as a professional learning network. The development of the communities in these studies is conceptually different from the development of the formal and informal communities examined in other sections of this review in that these communities are self-generated. These communities were not developed for a specific study, had no connection to an organization, and were not facilitated by an organization. Participant activity in these communities was completely voluntary and often anonymous. These studies illustrate

why some teachers engage in this form of independent learning, and how the affordances and constraints of this mode differ from those in formal and informal learning modes.

Alderton et al. (2011) illustrated how ten teachers used Twitter for their PLNs through an analysis of their *tweets* (messages posted in Twitter) and survey data. In this study, teachers reported building connections with others as the primary reason for their participation, and while this affordance is echoed in studies in the formal and informal sections of this review, researchers in this study suggest a greater degree of access to others is possible in this model due to the larger population of Twitter users. Teachers in the study in less mainstream content areas, such as calculus, reported accessing peers teaching in the same area, something not often possible in their schools or even divisions due to the low numbers of teachers in these areas. For example, smaller school divisions may have only one or two calculus teachers, therefore limiting collaborative opportunities though formal or even organizationally developed informal platforms. Teachers in this study also reported developing greater confidence in their professional practice through their interactions on Twitter. This increased confidence may be due to the ability of participants to engage in global conversations, discuss their practice, brainstorm, and share resources relevant to their practice with peers through these larger and more diverse communities. Teachers in the study reported learning about new technology tools for teaching such as blogs, Animoto presentations, voice threads, Wallwisher, Maps101, and Nings. They also reported receiving on-going support for implementing these technologies through their interactions on Twitter. While meaningful collaboration through 140 characters or less (the limit for individual postings on Twitter) may appear difficult, nine out of ten teachers in this study reported examples of collaboration with

peers that resulted from communications through Twitter. Teachers cited co-conducting projects between classrooms, co-presenting at conferences, co-writing book chapters, and sharing resources as examples. As well, all participants in the study reported taking connections created through Twitter to other forums, which perhaps suggests they move to other forums to allow deeper discussion and further follow through on ideas.

Participation in Twitter is one example of an independent learning activity, and despite the lack of research in this area there are several other self-generated communities available for independent teacher learning. While studies have been conducted concerning research-driven online communities of teachers, Hur and Brush (2009), recognizing the lack of research on self-generated online communities, designed a study to determine reasons for teacher participation in three of these communities. In their study, they analyzed online postings and interview data for 23 teachers who participated in three different online communities (Teacher Focus, WeTheTeachers, and Teaching community in LiveJournal), and reported teachers' five primary reasons for participation: (a) sharing emotions, (b) utilizing the advantages of online environments, (c) combating teacher isolation, (d) exploring ideas, and (e) experiencing a sense of camaraderie. While several of these activities could be facilitated through formal and informal communities as well, teachers in this study reported that independently chosen platforms often provided a safer place to discuss issues without fear of being viewed as incapable, and a community where they could ask for support without feeling intimidated. While this study did not provide specific technology tools or examples that were discussed, anonymity in these environments was reported as valuable. Researchers in this study also

suggest that the larger population in these communities combat the feelings of teacher isolation by connecting peers who relate to shared specific circumstances.

By examining the agents, activities, communications, development and tools of independent teacher learning in PLNs, we recognize many of the same affordances that can be attributed to formal and informal, but also identify additional affordances such as more timely access to emerging technology content and anonymous participation.

Participants in these types of communities are allowed greater agency in their participation levels, and greater choice in design of the community. Communities designed for research or developed by an organization often have population constraints due to the nature of the community, and while this can have positive implications such as localized collaboration within an organization (Schlager & Fusco, 2003), it may also limit the number of perspectives, the amount of resources, and the expertise in varied areas. PLNs often utilize a global community, thereby greatly increasing the number of participants. This may allow for very specialized networks to be developed, and specialized activities to occur around focused topics.

Communication through PLNs can offer anonymous participation. Teachers in one study (Hur & Brush, 2009) indicated that this ability to communicate anonymously often allowed them to discuss matters they did not feel comfortable talking about in organizationally sponsored or user-identified forums and they were able to receive support without the fear of negative peer judgment. Teacher communication through PLNs may boost confidence, offer a more comfortable environment in which to learn about new tools and resources, and help combat feelings of isolation.

The development of PLNs is solely dependent on the individual participants, and as such may possess many of the same constraints as informal COPS such as lack of organizational support and misalignment with organizational learning goals. In addition, effective participant activity in a PLN requires advanced knowledge of several social media platforms (Flanigan, 2011). While informal communities are often based around a single tool, an effective PLN is typically developed using several separate tools, each with its own culture and norms of participation, and since participation in a PLN is not organizationally based, there is usually no organizational training provided for teachers on how to utilize these tools.

The tools utilized in PLNs, drawing from a global and often real time updated system, may also provide more timely teacher discovery of emerging technologies, which in the current climate of ever changing technological innovation may provide teachers quicker access to ideas and tools than would be achievable though formal professional development.

Approaches to Supporting Teacher Learning that Combine Modes and Models

In their review of the literature on science teacher learning about technology integration, Higgins and Spitulnik (2008) suggest that professional development through formal and informal interactions with colleagues and researchers can be effective in helping teachers successfully integrate technology into science instruction and note that successful integration of technology is linked to conversational opportunities between teachers to discuss technology integration ideas. As well, Barab et al. (2003), in their study of the development of a web-based professional development system, termed the

Inquiry Learning Forum (ILF), designed to support a community of practice, suggests similar findings:

> We have experienced our greatest success when online interactions in the ILF have served as extensions of face-to-face workshops, meetings, and classes, or when we being together individuals that had previously interacted only in online settings and allow them to develop relationships outside of the e-ILF (p. 252).

These findings, while not empirical studies concerned with technology integration, are echoed in the two studies in this section we located for this review (Mackey & Evans, 2011; Vavasseur & Macgregor, 2008). In both studies, technology integration is the focus of the teacher learning experiences, and while not solely focused on science as the content area, both studies include science teachers as participants. In the first study, Mackey and Evans (2011) examine the complementary connections between formal learning experiences provided through university courses and informal COPs. In the second study, Vavasseur & Macgregor (2008) examine the use of an informal online COP to determine how it extends the formal learning experiences provided by an organization. These studies focus on the affordances of combining modes of teacher learning, and describe the benefits of this type of teacher learning for technology integration.

Mackey and Evans (2011) conducted a case study of 15 teachers in an online information and communication technology (ICT) graduate diploma program. They collected participant interview data, online activity records, and peer interview data between 2005 and 2008, and concluded "there are strong links between social learning theory, formal online learning opportunities, and authentic learning in communities of practice" (p. 3). The graduate program was designed to assist teachers in learning about pedagogical uses of ICTs, and teachers in the program described incorporating Web 2.0

tools, web quests, concept-mapping software, and learning management systems into their instruction as a result of their experiences in the program. Teachers in the study described how the informal, face-to-face learning with colleagues in their workplace affected, and was affected by their formal learning processes in the online program. Using the theoretical framework of communities of practice (Wenger, 1998), as well as connectivism (Siemens, 2005) as lenses for this study, researchers described how teachers developed their own networks of practice both within their workplace and within their online communities of practice. Teachers in this study naturally combined their learning from the formal coursework with peer learning from informal conversations, and through collaboration and the sharing of student work, peers were influenced as well by the formal learning activities undertaken by the teachers. The researchers of this study suggest that by re-designing formal learning experiences to encourage participants to adapt the learning to their workplaces and share the knowledge acquired informally with their colleagues, technology integration ideas and strategies may be more fully supported, more effectively implemented into practice, and more widely disseminated through an organization.

In the second study, Vavasseur and Macgregor (2008) examined an in-service teacher professional development program focused on the implementation of a module designed to facilitate the integration of technology. The program was designed to incorporate formal face-to-face learning experiences with informal learning experiences facilitated through a virtual COP. The focus of this program was derived from teacher and principal surveys that indicated a concern about the ability of teachers to implement a newly mandated state curriculum that required greater technology integration into

instruction. The program focused on using technology as a tool for productivity, research, and communication, as well as exposed teachers to the National Educational Technology Standards for students and teachers. Teachers from two middle schools were divided by school and content area with mathematics and science teachers from a single school assigned to one group and English and social studies teachers from a single school assigned to another. As well, principals from each school were also assigned to both groups based in their schools. Face-to-face sessions were conducted twice per week, and the Blackboard learning management system was utilized to facilitate discussions about the face-to-face sessions and facilitate peer support. This mixed-methods comparative case study utilized teacher surveys, data derived from teacher performance on a technology-enhanced unit plan, focus group interviews and analysis of online threaded discussions to examine the interactions among teachers in the study, their perceptions of school leader participation in the online community, and the effects of this experience on their sense of efficacy and their ability to develop and implement technology into their content areas. Teachers in the study reported valuing the informal online conversations for both moral support in implementing new technologies and sharing of ideas and resources. Teachers reported gaining competence in using technologies such as digital spreadsheets for graphing survey results, web quests, and Trackstar. Teachers also reported learning about, and supporting each other in the use of blogs in the classroom, and general strategies for using laptops and the Internet with students for research.

By combining modes and models, the communities described in these studies illustrate new affordances not previously identified through the studies focusing on single modes of learning. Community activities are both organizationally supported through

formal learning experiences, which aligns them with organizational goals, as well as informally supported through informal COPs that provide just-in-time and on-going support.

As well, the participation of principals in the informal community in the second study provided improved communication between school leaders and teachers, and helped align organizational and teacher learning goals. Improved communication among teachers in these studies facilitated dissemination of knowledge acquired through formal modes of learning throughout the organization through informal modes.

Finally, informal and independent learning activities typically do not benefit from organizational supports such as community moderation and provided free time for participation in learning activities. However, as noted in the study by Vavasseur and Macgregor (2008), shared agency of the community by the organization leaders and the teachers allowed for effective, focused discussions in the online community and created alignment with organizational goals.

Summary

Table 1 summarizes the affordances and constraints of the three modes of learning in the studies reviewed above. This table categorizes the affordances and constraints identified in the previous sections by agents, activities, communications, development, and tools.

Formal learning activities inherently possess organizational support, which assures alignment between teacher's opportunities to learn and the learning goals of the organization. Further, organizational support can moderate community communication to maintain focus on relevant topics and support localized collaboration. However, the

community is built from a single organization's population, thus limiting the perspectives and diversity available. This mode of learning is best suited for district-wide initiatives, as the organization can provide training, tools and expertise for a specific initiative, and be confident that all teachers will be exposed to these resources, but it lacks the resources to develop training that will suit the learning styles and needs of every teacher. While this mode of learning improves communication among teachers, among school leaders, and between teachers and school leaders, it lacks teacher voice and experience in the learning processes and content.

Informal learning activities can provide continuous, on-going and just-time support, and align with several identified elements of effective teacher learning such as collective participation of teachers and duration of learning activities. Informal learning also allows for teacher experience and choice to be considered, which in turn allows for teachers' context and composition of the communities in which they work to be considered. The flexibility of informal learning may also assist teachers in overcoming the time barrier that is often cited for participation in learning activities. However, without organizational support, participants, who may not possess the required expertise, are solely responsible for informal learning effectiveness. As well, free time during the workday for participation in informal learning activities is typically not provided. Finally, informal learning activities may introduce additional problems with information overload, misalignment of teacher and organizational learning goals, and difficulties in developing platforms to facilitate informal learning.

Independent learning activities in communities shares many of the same affordances and constraints as informal modes, but may provide a greater degree of

autonomy, a larger base of resources, faster access to emerging technologies, and benefits associated with anonymity. The communities available for independent teacher learning generally exist on a global scale. This not only increases the resources and people teachers have access to, but can also can provide a level of anonymity teachers report as advantageous. As well, with greater access to more individuals, teachers may more readily locate individuals who share similar concerns or teach in similar content areas. Information concerning emerging technologies may also be available quicker on these networks than through organizationally sponsored training, which takes more time to design and develop. However, much like informal modes of learning, independent learning activities may lack organizational supports such as provided free time during the workday to participate and training in the use of independent learning skills and platforms. While resources and expertise through PLNs are unlimited, participants may need advanced knowledge of several technologies and platforms to effectively utilize this model of learning.

Literature is starting to emerge that examines the affordances of combining modes of teacher learning. By combining formal and informal learning activities, studies suggest that knowledge acquired through formal modes may be effectively supported and disseminated through an organization through informal modes (Mackey & Evans, 2011). A hybrid model utilizes the affordances of both modes of learning to counteract the constraints of each. For example, informal learning activities can benefit from the formal organizational support in terms of provided free time during the day for participation or community moderation, and in turn the formal learning activities can benefit from informal on-going and just-in-time support.

Discussion

The majority of research in this review focuses on a single mode or model of teacher learning, and in doing so illustrates specific affordances of that mode or model. Yet, the research also illustrates that teachers in fact make use of all three modes. Taking a teacher viewpoint of learning suggests we should review these modes and models from a holistic perspective. By applying the analytic lens of the various elements of social learning within community, we begin to see patterns among their affordances and constraints, and therefore how educational organizations (i.e., schools, districts, professional organizations, schools of education) could take such a holistic approach to supporting teacher learning and develop leadership practices and associated tools, routines, and structures to purposefully make the connections among modes.

Agency in formal learning activities is held primarily by the organization. This allows for organizational facilitation of community that can provide expertise not available to teachers through independent or informal learning activities. Formal and informal modes both promote local collaboration, a constraint in independent modes, but when teachers draw upon all three of these modes, that constraint of independent learning can be addressed. For example, a teacher doing independent research on a new technology through a PLN could utilize informal learning with colleagues to better adapt the new technology to the local environment, or brainstorm with colleagues to develop new ways of using a specific technology. A teacher leveraging the reciprocal nature of the learning modes allows for their learning to be better contextualized and better disseminated through an organization as well. This example also illustrates the affordance of increased perspectives and diversity of independent learning through PLNs.

The larger population of participants in the global networks often utilized for independent learning through PLNs offers a depth of perspective and diversity not realized through informal and formal modes. This infusion of new ideas through these global networks allows teachers to then build upon them in local collaborative work done in informal and formal modes.

Instead of leaving to chance whether teachers develop informal and independent networks for learning and then draw upon them to continue efforts begun in formal learning, educational organizations can develop or adopt digital or analog tools, routines, and/or structures to purposefully make the connections among modes. Expertise in areas of need for an organization and potential local collaborators could be identified by tools that allow individuals to tag or otherwise label their expertise and interests, and then disseminated among informal and independent communities with robust search features to allow others to subscribe to these individuals identified with expertise of interest to them. Aggregating its members' output of various PLN tools (e.g., Twitter feeds of its members) into a central location, an organization could extend the reach of anyone's single PLN, while also organizing its resources in terms of organizational goals. Leaders could develop practices that comb these aggregated information streams that make teachers' informal and independent modes more visible both to see how topics introduced in formal PD are being taken up (e.g., as search terms) but also to seek out new ideas that should be brought into formal PD (e.g., trending topics).

Formal activities align with organizational goals as well as enjoy the support of the organization, neither of which is inherent in informal or independent learning activities. However, formal activities suffer from inadequate on going and just-in-time

support, which is more effectively done through informal activities. When teachers combine the modes, not only are these identified constraints addressed, but new affordances in each mode are realized. For example, teachers could utilize peer support from informal learning environments to assist with the classroom implementation of a new technology they were exposed to through a formal learning activity. Teachers could then collect additional resources on this topic independently, and share these resources with peers. The formal learning is not only better supported and better disseminated through the organization, but expanded on as well.

Again, there are tools, routines, and structures that an organization's leadership can establish to increase organizational participation in informal and independent communities, and thereby better align and more seamlessly connect its teachers' and the organizations' learning goals. Leaders modeling and setting a tone for the use of PLNs and informal communities would help to bring those resources for teacher learning into the organization and knit together some of its members' interactions so that formal learning activities could benefit from on-going and just-in time peer support. As well, promoting that it is a culturally acceptable norm for teachers to use their work time to build stronger ties with these informal and independent communities would help organizations to benefit from the collective knowledge of the global community.

Tools for independent learning, while requiring training to utilize, provide unlimited resources and more current access to emerging technologies, whereas formal and informal tools are typically constrained to organizational resources and slower to react to new technologies. For example, teachers who wish strongly enough to build ties with particular informal and independent communities, like the maker community, also

train themselves on using the associated hardware, software and protocols. Some teachers also get drawn in by the possibilities they imagine with a new tool, and may find a whole new community of peers exploring its use in the classroom, such as with 3-D printing, robotics and electronics.

Were educational organizations to make the effort to pull together and provide tools associated with each of these modes for members use, they could provide unlimited and up-to-date resources for teachers' use. Organizations that provide training on informal and independent tools by proxy provide teachers quick access to unlimited resources and emerging technologies that are typically unavailable through formal learning activities. This might mean providing teachers with the installation of any necessary PLN tools or plug-ins, formal learning activities on the development, creation and responsible use of a PLN, time in the workday to engage in this type of behavior, and an informal means of communicating the knowledge gleaned from the activity.

While different types of communication are possible in each of the three models of community, each model displays distinct affordances. Formal communities, being organizationally sponsored, are able to utilize the organization to locate outside expertise not available in informal modes and often difficult to locate in independent modes. Informal communities infuse teacher voice and experience in the community and can often better situate learning in teachers' environments. Independent communities can offer anonymous participation, and provide teachers feedback without fear of being viewed as incapable. Teachers could work to combine these three communication channels to more naturally and holistically address their own needs. For example, teachers could seek out their grade level and content area peers to discuss and utilize in

more specific ways outside expertise from formal learning activities, thereby also building routines that obtain just-in-time and on-going support via these informal collaborations with peers. Finally, teachers could anonymously discuss these activities, and receive advice from a global audience about these activities through their independent PLNs; this may be motivated in part by wanting to reach a greater number of peers in their specific content areas, which is often difficult, to refine their implementation of these activities.

We see here how educational organizations could better weave together the three modes of learning through the use of leadership practices that employ online and non-digital tools, routines, and structures so as to leverage the expertise they are able to introduce into their organizations, which in fact might be either unavailable or difficult to locate in informal and independent communities. For example, through participating in informal communities organizational leaders could establish two-way communications that could serve as a feedback loop if the teachers' voices are used to improve formal learning activities. By participating in informal communication, educational organization leaders can model culturally accepted norms of behavior so that teachers expand on learning begun in formal professional development, reflect on the practices learned, and apply new practices learned to their local setting. By allowing teachers opportunities to participate in anonymous communication through PLNs, organizations provide safe outlets for teachers to discuss issues they feel are inappropriate for organizational affiliated communities. As well, organizational leaders could develop practices to engage in these communities to receive un-edited feedback about school related issues.

The development and facilitation of any model of a teacher learning community is a non-trivial task, yet as the research in this review shows teachers do seek out all three modes. Imagining from their perspective why they make such effort, we can speculate it is to add in a self-selected topic from a global knowledge base on top of the moderated and supported—but also limited—community they may enjoy in their formal models. For example, teachers who self-initiate participation in virtual worlds like Second Life, may then bring elements of this technology into their formal communities.

Were the leaders of educational organizations to make efforts to seamlessly provide teachers access to training and support of all three modes of communities it could infuse the organization with new ideas and technologies from teachers' PLNs, support collaboration on these ideas in informal school-level communities with their peers, and foster sharing with the entire organization through its formal communities. To create such a holistic model, leaders would need to develop or adopt new leadership practices that incorporated the tools, routines, or structures that would generate interactions among these communities. For example, the educational organization could provide for the aggregation and collection of information streams stemming from global Internet-based communities, such as on Twitter, and a member of the formal learning community could be assigned to add effective moderation and curate what could otherwise seem like information overload to some teachers. These information streams could be built into formal and informal networks as described earlier, and teachers might then gain access to others who can provide assistance in their content areas and select useful resources for others in the organization. Were leaders to adopt new practices that assisted teachers in navigating these global networks, it would not only provide a valuable resource to

teachers but also make it likely that teachers would provide valuable resources back to the organization.

Conclusion

We call here for combining the modes and models of teacher learning examined in this review into a holistic model of teacher learning, incorporating formal, informal, and independent learning modes. Were organizations (i.e., schools, districts, professional organizations, schools of education) to take a holistic perspective and weave together formal, informal, and independent modes of community-oriented models of teacher learning they could leverage the affordances of each mode to fill in the gaps of the others. Teachers already model this holistic approach, utilizing informal collaborations for support in implementing technology projects they were exposed to through formal learning activities, and developing ideas of their own and sharing them with their peers informally, but do so without support in the form of time and training from the organization. What organizations lose by focusing primarily on formal learning activities is the opportunity to build on their initial investment in a teacher's learning experience. Given that effective science teacher learning of technology integration requires on-going support (Higgins & Spitulnik, 2008), it stands to reason that exploring all opportunities to expand organizational supports is warranted.

Our recommendation for organizations concerned with teachers' learning to adopt a holistic model of providing such opportunities requires recognition of the affordances and constraints of each of the three modes of teacher learning and has several implications for implementation. While informal and independent learning cannot be developed by an organization, structures and platforms can be provided to facilitate these

learning activities. A holistic model reflects much of what teachers typically already do, and the primary challenges in developing it will be concerned with identifying synergistic relationships between learning modes, implementing new organizational supports and leadership practices for independent and informal activities, and understanding effective design utilizing the three modes. Development of such a model is a non-trivial task, and future research, especially in the areas of independent and informal learning as well as hybrid models, will greatly inform the process. Development and implementation of such a model may have the ability to not only improve science teacher learning of technology integration, but improve organizational learning in this area as well.

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Table 1

Affordances (+) and Constraints (-) of Three Modes of Learning, By Conceptual Framework Element

	Formal	Informal	Independent
Agents	+ Organizational Facilitation - Limited perspectives + Promotes localized collaboration	- Lacks support of organizational facilitation + Promotes localized collaboration	+ Managed by the individual + Increased diversity and perspective + Large population of participants
Activities	+ Alignment with organizational goals + Provides district or school wide training efficiently - Lacks teacher input for learning processes and content	- Lacks alignment with organizational goals +Allows for teacher input on learning processes and content - Lacks organizational support in terms of provided time + Provides flexibility in time + Provides peer support	- Lacks alignment with organizational goals + Provides timely access to emerging technologies + Allows for specialized, content-specific activities
Tools	+ Provides communication tools - Requires ability to use technological tools - Limited resources	- Lacks organization support for training with tools - Limited resources	- Lacks organizational support for training with tools + Unlimited resources + Tools possess more current access to emerging technologies -Requires knowledge of several tools
Communications	- Lacks teacher voice and experience + Provides outside expertise + Improves communication between teachers, leaders, outside participants	+ Allows for teacher voice and experience + Improves communication between teachers and outside participants - May suffer from information overload - Limited expertise	+ Allows for anonymous communications + Access to outside expertise + Improves access to content specific peers
Development	- Limits participant population + Organizational facilitation ensures effective development/ redevelopment	- Difficult to design + Allows for teacher choice in level of participation - Lacks organizational facilitation	+ Provides global participant population - Lacks organizational facilitation

Running head: SCIENCE TEACHER PROFESSIONAL LEARNING ACTIVITIES

The Modes, Tools, and Behaviors Science Teachers Engage In During Professional Learning Activities

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Abstract

This study examined the modes, tools, and behaviors four science teachers in one department engaged in during their professional learning activities for technology integration. This examination of four science teachers involved in the first pilot year of a research and development project provided a focused examination of these teachers' actions. Through the use of both weekly quantitative surveys and a series of three qualitative individual interviews we developed an illustration of their learning processes and activities. We investigated the connections between formal, informal, and independent learning modes, and examined how each mode affected the others. Four primary findings were identified. First, teachers in this study collectively reported engaging in the highest numbest of informal learning activities for learning about technology integration. Second, teachers utilized independent learning activities frequently and viewed them as pervasive parts of the professional lives. Third, teachers in this study recognized the interdependent nature of the three learning modes, and fourth, teachers reported numerous shortcomings of the formal learning opportunities available to them through their school division. The findings of this study contribute to understanding how schools and school districts can design, create, and implement effective, holistic teacher learning programs for technology integration in science instruction, particularly with the support of a virtual learning environment.

The Modes, Tools, and Behaviors Science Teachers Engage In During Professional Learning Activities

Our previous research suggests that science teachers engage in three modes of learning about technology integration: formal, informal, and independent (Jones & Dexter, 2012). This framework is echoed in the research on workplace learning in which the three learning modes are described as formal, informal, and incidental (Marsick & Watkins, 1990). School divisions currently focus primarily on supporting formal learning activities; but by doing so limit the nature, frequency, and duration of teacher learning and miss opportunities to build collective teacher knowledge within the organization (Jones & Dexter, 2012).

In the context of a research and development project, a web-based application and curriculum was created to investigate how to bring together and facilitate each of these three learning modes. The project aspired to create an online space that promoted the learning goals a school sets for all its members as well as support individual teachers in reaching their personal learning goals, and then align the two by tying together formal, informal, and independent learning activities. So as to support each of the three learning modes, the larger project developed a formal professional development (PD) program for leaders' facilitation of teachers' technology integration and then investigated how various software features could also meet teachers' needs for on-going and just-in-time support, create opportunities for collaboration, and aggregate and share teacher knowledge. The online component of the project is the learning environment (CANLEAD.net), which supports asynchronous learning experiences to minimize the geographic and temporal

constraints of traditional face-to-face learning experiences and allows for "anytime/anywhere" collaboration between participants.

Within the context of the feasibility study underway during the project's first pilot year, we examined the learning modes, tools, and behaviors that four middle school science teachers engaged in for their professional learning activities for integrating technology into their classroom instruction at one school during the second semester of the pilot study, and the summer and fall semester that followed (i.e., January to December) so as to investigate time periods under which we'd anticipate formal, independent, and informal learning would occur, respectively. We investigated the connections between formal, informal, and independent learning modes, and examined how each mode affects the others. The findings of this study contribute to understanding how schools and school districts can design, create, and implement effective, holistic teacher learning programs for technology integration in science instruction, particularly with the support of a virtual learning environment.

Literature Review

The use of technology is pervasive in science instruction, as the field of science often depends on technological tools (McCrory, 2008). Preparing teachers to effectively integrate technology into their instruction requires a definition of what they should know to be able to accomplish this. Technological pedagogical content knowledge (TPCK) is a conceptual framework useful for understanding teacher knowledge about technology integration (Mishra & Koehler, 2006). This conceptual framework considers technological, pedagogical, and content knowledge as three connected components that should be considered together when designing instructional activities. Each component

affects the others, and decisions about each will include considerations of the other two. This framework differs from traditional views of technology integration where technology is often considered as a stand-alone component. Using this framework to consider teacher learning of technology integration situates the technology in the context of the content and the pedagogy, and by doing so provides teachers more authentic and relevant learning experiences for understanding how to use technology for instruction as opposed to learning about the technology and how to use it for more general purposes (Mishra & Koehler, 2006).

McCrory (2008) examined TPCK in science instruction, and suggests three aspects teachers must consider. First, teachers must know where in the curriculum to use technology, an aspect that can be considered in terms of both pedagogical and scientific uses. Second, teachers need to understand what technology to use. This aspect requires consideration of technology used in the service of science, in the teaching and learning of science, and in the doing of science. Third, teachers must know how to teach with technology. This aspect requires teachers to consider such issues as teaching students to use the technology, identifying likely failure points for the technologies, organizing the classroom for the activities, and planning for assessment of what students learned. McCrory acknowledges that TPCK must consider a teachers' specific context, making broad professional development in this area is difficult. McCrory suggests, however, professional development designed to equip teachers to learn from their practice and from on-going education may result in positive implications. This type of teacher learning may be best realized through teacher learning communities.

Most research on teacher learning activities for technology integration focuses on single modes or models for teachers' learning communities. Formal modes of teacher learning are often examined through professional learning communities (PLCs) (Graham, 2007; Hamos et al., 2005) and online professional development (Dede, Breit, Ketelhut, Mccloskey & Whitehouse, 2005). Informal teacher learning is often examined in terms of informal communities of practice (COPs) (Ming, Wah, Azman, Yean, & Sim, 2010; Riverin & Stacey, 2008; Rodrigues, Marks, & Steel, 2003; Stevenson, 2004) , and independent teacher learning is increasingly considered in terms of community as well, called personal learning networks (PLNs) (Tu, Sojo-Montes, Yen, Chan & Blocher, 2012).

Formal teacher learning, often referred to as teacher professional development (PD), is defined for this study as learning experiences created and facilitated by schools or school districts. Much research has been conducted on traditional PD for science teacher learning of technology integration (see recent reviews of Gerard, Varma, Corliss, & Linn, 2011 and Higgins & Spitulnik, 2008), and typically examined face-to-face instructional methods. Researchers, however, acknowledged that using technology to support teacher communities was a needed area for future research (Higgins & Spitulnik, 2008). Online PD and PLCs are two current models for this mode of learning. Online PD may offer several advantages over traditional face-to-face teacher learning experiences by increasing flexibility, providing access to expertise not available locally, and providing improved on-going support (Dede, Breit, Ketelhut, Mccloskey & Whitehouse, 2005). However, many online formal learning experiences still lack the necessary level of on-going support, degree of flexibility and level of customization

needed by teachers. Formal learning experiences traditionally have a start and end date, and any development of community around the course, along with the included social learning elements, is constrained by these dates (Mackey & Evans, 2011). The timing of these experiences may not coincide with when teachers most need support and guidance in implementing a new technology; a gap often filled through informal interactions between teachers (Jones & Dexter, 2012). Formal learning experiences rarely consider teachers' personal interests or experiences which may assist teachers in connecting their learning to professional contexts (Mackey & Evans, 2011). PLCs seek to eliminate the isolation many teachers feel, and facilitate collaboration between teachers (Hamos et al., 2005), but operationalizing this practice is difficult, and PLCs are generally facilitated through face-to-face communication methods (Graham, 2007).

Informal learning experiences are those not facilitated by an organization (Marsick & Watkins, 1990); for example, face-to-face conversations and emails with colleagues (Wilson & Berne, 1999). Recent research on this mode of teacher learning has focused on the role of informal communities of practice (COPs) where people who share a passion for something, interact regularly to learn how to do it better (Wenger, 1998; Wenger, 2002). However, these communities often have little alignment with organizational goals, and rarely help build an organizational knowledge base that can be utilized by an organization for subsequent learning activities.

Independent learning activities originate from the individual, and are not necessarily related to organizational colleagues or resources. Teachers' engagement in this mode of learning might occur through weekend workshops, higher education coursework, activities connected to professional organizations (Wilson & Berne, 1999),

or even self-guided online research and exploration. Teachers develop PLNs when they create learning networks through one or more channels, and networking sites such as Twitter have provided platforms that facilitate this process (Alderton, Brunsell, & Bariexca, 2011). Independent teacher learning in PLNs allows teachers to collaborate with others and manage their own learning processes (Tu et al, 2012). This provides teachers with choice in their learning activities and level of participation as well as global access to peers and resources previously unavailable, but also typically requires technological competence with several different tools and may not provide alignment with organizational goals.

Each mode and corresponding model previously described inherently possesses both affordances and constraints. Formal online PD offers greater flexibility in terms of time and distance than traditional face-to-face methods, and PLCs provide teachers with a chance to collaborate and share resources. However, neither of these formal learning activities provide adequate on-going or just-in-time support, nor do they provide teachers' choice in their learning processes or utilize teacher experience. Informal COPs can provide improved on-going and just-in-time support, and independent PLNs can provide teachers choice in their learning activities; however, neither of these models can assure alignment between an organization's and teachers' learning goals.

A more holistic approach to supporting teacher learning activities could be created by organizations through facilitation of formal, informal, and independent learning experiences, as well as utilizing the synergies created by supporting each type (Jones & Dexter, 2012). While research about such holistic approaches is scarce, there are a few examples in the field of education. Vavasseur and Macgregor (2008) looked at

formal and informal learning experiences by combining an online community of practice with a face-to-face PD experience, and suggest the combination of the two modes can foster a successful collaborative experience. As well, Mackey and Evans (2011) extended this idea by examining how teachers studying for a graduate diploma utilized informal communities of practice to complete formal university courses and suggest there is considerable potential for online learning communities to support teacher learning.

In this study we examined the professional learning activities of four middle school science teachers within a formal PD initiative that had an ultimate goal of increasing their integration of technology to create multiple representations of concepts in their classroom instruction. Over the course of a calendar year, we examined teachers' participation in the formal PD, as well as any related informal or independent interactions that ensued, to understand the range of learning modes, tools and behaviors these science teachers used in developing and using technology-rich classroom instructional materials. This focus on the means of teacher learning is guided by the research question for the study: What modes, tools, and behaviors do science teachers engage in during professional learning activities for technology integration over one calendar year?

Conceptual Framework

To frame the data collection and analysis we drew upon the communities of practice conceptual framework (Lave & Wenger, 1991). Communities of practice are defined as the communities people form as they pursue shared enterprises over time (Wenger, 1998). A primary tenet of this theory is that engagement in social practice is a fundamental process by which we learn, which represents a departure from the idea that learning is simply the reception of information. As well, this theory describes the

different communities that people engage in, how styles of learning vary among different learning communities, and how participation in one community can affect participation in another.

This theory is well suited to describe the professional learning activities in-service teachers engage in as they work with colleagues to improve their craft through the use of technological tools. Teachers participate in several different communities of practice, including communities based around their departments, their schools, their divisions, their peers, their friends, and the larger global communities they may engage in such as ones developed through web–based social networks. By examining teacher learning activities through this framework, we were able to systematically identify how the modes, tools, and behaviors that were utilized by our teachers impacted the nature, frequency, and duration of their interactions. For example, formal communities such as PLCs dictate when, where, and with whom teachers interact. Informal communities are not governed by these regulations, but are often affected by location and the peers with which teachers work. Independent learning through PLNs originates with the individual teachers, allowing the greatest amount of choice in terms of the people they interact with and the nature of the interactions. These fundamental aspects of the different learning communities dictate the timing of the learning experiences and the tools that are employed. For example, formal PLCs, often being situated in teacher's schools, primarily employ synchronous, face-to-face learning experiences, while independent teacher learning through PLNs often utilizes asynchronous learning experiences utilizing communication technologies such as web-based social networks.

The communities of practice framework drew our attention to these characteristics of the different learning communities, and allowed us to identify affordances and constraints of each type of community. As well, this conceptual framework provided a lens for both examining an individual's participation in multiple communities of practice and describing how multi-membership benefits not only the individual, but the various communities as well. This theory of multi-membership provides a framework to guide the analysis of the effects one community may have on the others, and the implications these synergies between communities may have on teacher and organizational learning goals.

Wenger's earlier conceptions of this theory (1991) suggest that communities of practice cannot be developed by an organization but instead arise organically as the learning needs of members often require access to resources beyond the confines of an organization. However, he later articulated how organizations can create or provide structures that support the formation of learning communities (Wenger, 1998). This evolution of the theory allowed us to consider organizationally developed teacher learning communities alongside teacher originated learning communities, understand the differences in each, identify the effects of one community on others, and to consider holistically the various communities in which teachers learn.

Context of Study

The CANLEAD Project

In the summer of 2012, as a part of a professional development experience called CANLEAD, a technology leadership team from this school was provided with face-to-face instruction during an initial three-day session and a follow up one-day session. This

team was formed for this opportunity and was comprised of the principal, a technology support person, and a teacher leader in math and science. During these interactions instruction was provided about leadership best practices, technologies with specific affordances for math and science instruction, and ways to utilize the CANLEAD.net learning environment for promoting teacher learning about technology. Instruction also addressed how leaders could use the TPACK conceptual framework (Mishra & Koehler, 2006) to frame teachers' learning to integrate technology into instruction. The technologies presented were selected because of their ability to let teachers offer multiple representations of concepts. For example, probeware, such as voltage probes and related software, can allow students to measure electric current. They are given the opportunity to see electrical currents represented numerically, something only possible with this type of technology. As well, digital images allow students to see things that cannot be seen by the naked eye, allowing them privileged views of very small objects or objects that are otherwise inaccessible without this type technology.

During the first face-to-face session, the school leadership team collaboratively decided on which technologies would be implemented, and began the process of structuring the CANLEAD.net environment to support their school's math and science teachers' learning to operate and implement these technologies. In the fall of 2012, the group reconvened to discuss the implementation plans that were created and to collaboratively work together to refine these plans. Throughout the 2012-2013 school year the leadership team committed to supporting the math and science teachers at the school in learning about integrating the recommended technologies. The project's theory of action was that by changing how leaders supported teachers' opportunities to learn to

integrate, it would impact both teachers' interactions during learning as well as their classroom teaching, and ultimately their use of multiple representations in teaching would increase student achievement. During the time period reported upon here, the project was testing the feasibility of our approach of training leaders to work with teachers, and the usability of the materials developed to date; those data informed our iterative project design. That larger study also provided the opportunity to take an in-depth look at the professional learning activities teachers engaged in during that same time period.

Features of The CANLEAD.net Learning Environment

The CANLEAD.net learning environment contained the project-developed PD materials in an environment where the school leaders could change the content as they decided how and when to present it to teachers, and all participants could informally learn and communicate with each other and independently locate and interact with people and resources of interest. The software also has a survey module we used to generate the weekly surveys and their results, as described in the following section.

The CANLEAD learning environment provides leaders with technology integration model lessons using the recommended technologies, resources aligned to state learning objectives that could be integrated, and protocols for how leaders might engage teachers in learning with and then integrating such materials. Resources, such as student worksheets for data collection, links to virtual simulations, and examples of student spreadsheet templates were provided for download. Instructional videos were linked to the model lessons on how to operate the technologies themselves. Teachers could participate in asynchronous discussions, upload and download lesson plans and resources, and asynchronously provide support to each other. The tool thus eliminates temporal and

geographic constraints so teachers could work together in an on-going or just-in-time basis. All project-provided resources were tagged and searchable as were the profiles of all participants.

Methods

To best examine professional learning activities in the context of the teachers' school setting we selected a mixed-methods methodology (Creswell & Plano Clark, 2011). This choice reflected our beliefs that one data source alone would be insufficient to answer our research question. Through use of an explanatory sequential design, we were able to utilize the survey data to inform our qualitative methods, and in doing so allowed qualitative interviews to help explain the quantitative survey findings (Creswell & Plano Clark, 2011). By utilizing electronic spreadsheets to aggregate quantitative survey data we were able to identify trends in the data, and then subsequently allow our teachers to respond to these trends through individual interviews. The small population was chosen so that a focused description of their professional learning activities could be produced, something not well suited for a larger population and statistical analysis (Merriam, 1998).

Subjects

Four of the six science teachers from one of the middle schools engaged with the CANLEAD project were recruited for this study. Two science teachers in the school did not participate in the study as one was on a leave of absence for an extended period of time during the study, and the other was not participating in the larger study of which this research was a part. Two of the participants taught eighth grade science, one taught sixth grade science, and one taught seventh grade science. One of the 8th grade science

teachers was also the department chair for the school science department. The school is situated in a district that was recruited for the larger project that involved math and science teachers from all middle schools in the district based on their willingness to participate in the project. The school was chosen for this study due to their demonstrated abilities in informal and collaborative learning and so was designated the best case site offering an opportunity to learn. While both the Math and Science departments in this school participated in the program, the science department was singled out for this study to allow for a more focused description of the individual teachers' and department's professional learning activities for technology integration.

Measures

To examine science teachers' professional learning activities over time, weekly individual survey data was collected and individual interviews were conducted at the end of spring, summer, and fall of 2013. The weekly surveys, collected online, provided data about individual learning activities teachers engaged in, including the tools they used both within and outside of the CANLEAD.net environment during the previous week, as well as what technologies they interacted with and what science content they planned for or taught. The weekly surveys required teachers to only recall their learning activities for the past seven days, placing their reporting times close to the time of the activities. The surveys also asked teachers about the nature and the types of learning interactions that occurred in the previous week. For example, teachers indicated if discussions occurred around lesson plans, student work products, or topics and possible technologies. As well, they were asked to indicate whether these discussions occurred in person, in a meeting, in an online environment, or through another method (see appendix 1).

To develop the individual interview protocols, prior to each interview each teacher's survey data was used to create a summary of the activities they had reported in the months prior to the interview (i.e., from January 2013 until the spring semester interview in May; from latter May till the summer interview in August; and from September until the fall semester interview in December). These summaries allowed them to reflect upon and explain trends seen in their individual survey data. For example, if a teacher reported a consistent level of activities throughout a period, but then reported no activities for a week, interview questions were developed to address this gap. As well, if specific activities were reported only for one or two weeks during the period, interview questions were developed to understand why.

The interview protocols were also designed to solicit additional information from teachers about their professional learning activities, as well as provide insight into group trends identified by aggregating individual survey data and allow for their narratives to provide a more detailed description of both their individual and group learning activities for technology integration. For example, in the first interview period only one technology, digital images, was reported as being used by every teacher. Did the department adopt this technology together as a group? Did one teacher introduce this technology to the others? Was this technology the focus of a school-wide initiative? To better understand the nature of why all of the teachers used this technology during the same time frame, interview questions were developed to address this trend.

By allowing the interview protocols to be informed by the survey data, teachers were able to assist in the analysis of this data. They provided valuable explanations of the identified trends, and were able to provide a more detailed description of their

professional learning activities than would be possible through surveys only. By exposing them to their own aggregated survey results, they were able to get a unique view of their own professional learning activities, and use this information as a starting point for their narrative descriptions.

Data Analysis

To allow for a focused and sustained examination of the professional learning activities teachers engaged in about technology integration over time and to provide insight into when they engaged in the different modes of learning, each activity from the weekly surveys was categorized by formal, informal, and independent learning modes. For the purposes of this study, formal learning activities were defined as those that were organizationally sponsored or created. Informal learning activities were defined as those not explicitly required by teachers but carried out with school or district colleagues, and independent learning activities were defined as those not associated with content and technologies included in the formal development activities or not carried out with school or district colleagues. (See Table 1.)

By aggregating all four teachers' records, we were able to gauge the number of formal, informal, and independent learning activities these teachers engaged in throughout the year. By comparing the individual teacher's data and further aggregating individual teacher data by department, a glimpse of the community learning activities emerged. By looking at the data through the lens of the communities of practice framework (Lave & Wenger, 1991), we examined how teachers in the same grades, or in different grades, collaborated throughout the duration of the study, and identified when these collaborative activities occurred.

Individual teacher interviews were recorded, with the permission of each teacher, transcribed, and entered into the Atlas.ti qualitative analysis software program. The coding scheme is shown in Table 2. The focus was on descriptive, not inferential, codes so as to address the research question and exploratory nature of this study. After initial discussions about the coding scheme were conducted, and agreement among authors was reached on coding protocol, the transcripts were coded by the first author.

Results

During the study, each teacher was asked to respond to 40 weekly surveys. The total response rate was 49%, with the response rates for individual teachers ranging from 30% to 73%. Through analysis of this quantitative survey data and the qualitative interview data, four primary findings were identified. First, despite receiving little organizational support for informal learning activities, teachers in this study collectively reported engaging in the highest numbest of informal learning activities for learning about technology integration. Second, while the teachers in this study reported engaging in very few independent learning activities on the surveys and received little support from their schools to engage in these activities, analysis of the individual teacher interviews suggests teachers utilized these types of learning activities frequently and were a pervasive part of the teachers' lives. Third, all teachers in this study recognized the interdependent nature of the three learning modes, and fourth, teachers reported numerous shortcomings of the formal learning experiences available to them through their school division. Each of these four findings is discussed in further detail in the following sections.

Prevalence of Informal Learning Activities

Aggregate survey data from all four teachers in the study revealed that of all reported learning activities during the calendar year, 78% were informal, 20% were formal, and 2% were independent. The three most reported informal learning activities by all teachers were (a) discussing lesson plans in person (10%), (b) discussing topics and possible technologies in person (8%), and (c) sharing lesson plans by email (7%). In comparison, the two most reported formal learning activities were discussing lesson plans in a meeting (5%), followed by discussing topics and possible technologies in a meeting (4%).

A qualitative analysis of the individual teacher interview data suggests similar patterns. The four teachers in the study consistently spoke of collaborative learning activities and valued their colleagues as important resources. On teacher noted that in terms of learning about technology, "80 percent of what I do, if not more, is in collaboration". The department chair echoed the survey findings noting that in-person communications were her primary method for informal collaborations, and reported that teachers would engage in these types of learning activities "before, during and after school". Another teacher added that these informal meetings occur "unofficially, constantly", and often happen during their lunchtime. These in-person meetings were often conducted outside of organizationally provided time. When questioned about the formal meetings they attend, one teacher described her meeting schedule for the upcoming week and said, "We have Monday, Wednesday, and Friday. Now officially, according to our principal, we don't have to meet those days because it's not in our meeting time, but we will". Several teachers reported informally meeting during the

summer break as well. These meetings were held at their school, at their homes, and in other outside locations. Aside from in-person meetings, several teachers also reported using email, text messaging, and phone conversations for these interactions. One teacher reported that email communications from the librarian, the gifted resource teacher, teachers in other content areas, and friends teaching in other schools or districts were on-going, and often provided useful technology resources. These email communications continued throughout the school year and even during the summer break.

Teachers spoke most frequently of informally collaborating with peers teaching in the same grade level and content area. This is logical as the materials and content most align, providing teachers with the most benefit from the collaboration. One teacher noted that all Powerpoint presentations she created were shared with her peer in the same grade and content area. As well, teachers in the same grade level were also required to share hardware, which required working together to address scheduling concerns. Proximity also played a role in forming collaborative partnerships. One teacher noted that her colleague was located in the next room and this created "constant communication back and forth". As well, organizational alignment of planning times within a grade level also provided opportunities for grade level peers to work together.

Teachers in this study reported engaging in informal learning activities with district level personnel, librarians, and peers in other schools and/or districts. One teacher spoke of her extended learning network in this way, "there is a lot of networking going on, I know it is kind of un-documentable, but it's true". Teachers in this study often worked with district-level instructional coaches, whom are full-time resource teachers assigned to assist them with technology and other instructional issues. While this formal structure is

put in place by the district, one teacher noted working with an instructional coach in a more informal way, noting they were friends outside of school and would communicate outside of the normal work day, often using their private cell phones. Another teacher reported learning about new technologies from her students as well, indicating that some of her students were quite adept with emerging technologies. Another teacher echoed this practice when describing her learning activities for using a new digital fabricator: "I had to learn on my own how to use a silhouette printer, which was difficult. I ended up calling the high school and asking for some (students who had experience with this tool) to come down and help".

Teachers in the study articulated that these informal learning activities often provided a more effective tool for learning new technological tools. In discussing a formal learning activity that was provided to her about a new technology initiative, one teacher reported, "that gave me a little understanding of it. Then the big training was (another teacher) and I sitting down, and getting our hands on it". Informal learning activities were also reported as more beneficial due to the timing of the activities. Teachers noted that formal learning activities rarely aligned with when they needed assistance. One teacher described this situation: "we fly by the seat of our pants a lot of times. Then when we realize something we really want to incorporate, then we scramble around and grab a colleague that has done it"**.**

Under-reported Independent Learning Activities on Surveys

Teachers in this study, during the individual interviews, estimated anywhere between 30 and 90 percent of their learning activities about technology integration were conducted independently. One teacher stated, "I would say the actual work, the touching

the computer or whatever piece of technology, I would say is 90 percent independent". The teachers in this study were preparing to implement the Google suite of online tools, and when one teacher was asked to estimate the percentages of time she spent doing formal, informal and independent learning about this technology, she reported a third in each mode. Teachers in the study indicated valuing independent learning activities for learning about technology integration and articulated when this type of learning activity was most effective. One teacher described her independent learning by noting, "it's more difficult to do technology planning and looking for stuff together than it is to do it independently", and added, "I need to sit and play with (technology tools) and see if I feel like its workable for my kids".

Several teachers in this study reported that independent learning activities, such as using Google to locate and learn about technological resources, allowed them to make efficient use of their time. They reported being able to look for resources relevant to their content, teaching style, student demographics and physical location. One teacher stated, "I went looking with a purpose already", indicating her preference for searching for technological tools to fit her content as opposed to learning about a tool first and then matching it to her curriculum. Teachers in the study reported using Google, Pinterest, YouTube, the PBS website, education blogs, and other websites designed specifically for teachers as useful for locating information on new technologies. They also articulated that many times learning to effectively implement a new technology was a process of independent trial and error, and that hands-on experience and trying things out independently were the most effective ways for them to learn. Several teachers noted that even similar technology implementations in the same grade level and content areas

could have diverse outcomes based on the demographics and ability levels of the students in their specific class. In developing technology-rich instructional activities for their specific students, several teachers reported that their learning activities needed to be independent. One teacher added, "the spark has to be alone".

Several teachers in this study reported engaging in independent learning activities daily, often during non-work time. This type of learning was reported as often incidental and arising through personal experiences. One teacher noted: "It's quite often that morning or the night before that I see something, and I'm thinking, 'I want to share that with the kids'". With the ever increasing use of the Internet and social media, teachers in this study had access to a large body of resources, many of which they identified as useful for their teaching. They reported multiple times independently discovering useful resources on the Internet and not only utilizing these in their classrooms, but also sharing these with their peers. Several teachers described locating these resources as "stumbling" upon them, and one teacher reported, "I don't necessarily sit down and say 'I am going to sit and work on this'', but instead described finding resources more naturally as they navigated the Internet. Several teachers in this study spoke of the time flexibility that is provided through independent learning activities. With the abundance of resources available through the Internet, teachers were afforded the opportunity to engage in independent learning activities when it best fit their schedules. One teacher described this benefit in terms of exploring digital simulations on the Internet: "What's nice about technology is I can do that at five in the morning on a Saturday alone in my house instead of it has to be right here with a copy machine".

Synergies Between Learning Modes

One teacher reported that independent learning activities, especially searching the Internet for resources, were often the genesis of informal collaborations as located resources were typically shared with colleagues. Teachers also reported utilizing different learning modes for specific reasons. One teacher articulated that when she was solely learning about the technology she preferred to engage in independent learning activities so she could engage in hands-on activities, but then preferred collaborative work to better understand how these technologies could be integrated into her instruction. She noted for learning about the technology, "90 percent is independent and 10 percent is collaborative", but then explained that evaluating a technology and developing ways to integrate it into instruction occurred in about an inverse proportion. She described this independent/informal hybrid method of community learning by saying, "she creates some, I create some, and we come back together. It's independent, but the discussion piece is probably the most important, of why are we going to use it".

All teachers in the study recognized the synergies created between formal and independent learning activities as well. Most often the formal learning activities provided initial exposure to new technologies, and teachers then engaged in independent activities to develop ways to incorporate these technologies into their instruction. One teacher described this process as "I would take what I already had, I would take the piece from CANLEAD and would turn it into something that flowed". Another teacher commented, "The formal training definitely helped. I'm glad that I had it. It gave me the confidence to be able to go back and say, 'OK, I know how to do this. Let me show you how to get to that next step'". Several teachers in this study provided illustrations of how

formal and informal activities worked together. A teacher informally sharing knowledge gleaned from formal learning activities is one illustration of this combination of learning modes. One teacher illustrated this example: "I've been coming back to the grade level team and saying this is what I've learned about Google Drive and let me give you a condensed version of everything that I've learned about in my one day training in about 20 or 30 minutes, just an intro".

Several teachers in the study provided examples of how all three modes of learning are utilized together. This combination of modes would often develop from formal learning activities that presented new technology ideas, then independent learning activities would provide them with hands-on experiences with the technologies, and finally informal collaborations would provide peer support or inform how the technologies could be utilized in specific content areas and grade levels. One teacher described this process:

> If I hadn't had the formal training, I wouldn't know what (the technology) is capable of. I wouldn't get excited by it and want to try it. If I wasn't playing with it on my own, I wouldn't have the questions to ask the friend who's more efficient with it.

In addition, the school principal was beginning to recognize the benefits of supporting multiple modes of learning. During the summer break, teachers were allowed to engage in independent learning activities to prepare for the implementation of the Google suite of online tools and were compensated for their independent work. This combination of formal, as it was supported by the school division, and independent, as teachers were allowed to work on their own, demonstrated one combination of two modes. One of the teachers in the study expanded this learning opportunity to include elements of informal learning by talking to her peers and announcing, "I will be here this week if anybody else

wants to come in and work alongside me". Her affinity for informal learning with colleagues allowed for the development of informal learning opportunities, and demonstrated how by supporting one mode of learning, independent in this case, other modes of learning are also facilitated. In another scenario, the school principal asked one of the teachers in this study to independently go through tutorials for a new technology that was being implemented and report back on which ones were most useful. This information would be used to decide which tutorials would be utilized with the rest of the faculty. Here again, we see illustrated the use of independent learning activities to inform formal learning activities. Teachers in the study spoke favorably of the administration's attempt to combine learning modes, and one commented, "I really appreciated the fact that they (the administrators) understand that this is important and that they are funding it appropriately and not just saying you figure it out on your own time". She later commented that she felt as though the principal of the school was "respectful of our time".

Constraints of Formal Learning Activities

The school district in which these teachers were located focused primarily on providing formal learning activities to assist teachers in their learning of technology integration. The district provided training sessions, instructional coaches, outside technology experts, PLC time, and technology specific tutorials. Teachers in this study reported that many of these opportunities were beneficial, but noted several constraints in utilizing only this mode for their professional learning of technology integration. They reported lack of access to on-going support, little customization in the provided training sessions offered, lack of time flexibility, and lack of provided time during work hours to

participate in formal learning opportunities as constraints of this mode of learning. As one teacher commented, "I'll play around, look for stuff, look for resources, share resources with friends, but I'm not going in the building again", illustrating the reluctance of teachers to engage in traditional face-to-face formal training methods. Another teacher noted that provided training did not meet the demands of newly mandated initiatives, saying: "All these things were coming down, so I don't think the support, the collaboration, the in-service, and the training kept up with all the things they were saying we now do".

When asked about the formal learning opportunities provided by the division, several teachers reported a lack of customization as a primary constraint. Formal learning opportunities for technology integration were often described as overly general and at times not relevant to their specific needs. In discussing a district-provided workshop on the Google suite of online tools, one teacher said, "It was very frustrating…We need specific questions answered". Several teachers in this study acknowledged the difficulty in developing formal learning experiences that are specific to each of their grade levels and content areas, but reported little benefit to learning activities that they cannot align to their curriculum. Even within a content area, teachers often struggled to find relevance in the formal learning opportunities provided by their district to their specific curriculum. One eighth-grade science teacher noted of several formal learning opportunities, "if it is on science, almost always it's about life science or biology…it has nothing to do with me, and I tune out". She continued by saying, "it needs to be very specific to my subject and my level, and almost individualized". Several

teachers in the study reported that formal workshops were often either too advanced or too foundational, and they required differentiation along this spectrum as well.

Several teachers reported that formal learning activities rarely provided the required on-going support that is critical for successfully implementing new technology initiatives. One teacher stated, "there's a miss there between the support that's provided and what people need". Another teacher echoed this sentiment as well: "There's not any kind of support for that. It's 'try it, try it, try it, there's no risk'. There is a risk. There needs to be more support and more specific support". Another teacher reported that support is often required at times other than when the formal learning activities are conducted. She expressed her frustration about a specific district-provided workshop on using a new technology by saying, "I'm not going to do that until May. I'm not going to waste my time now".

Several teachers in this study echoed the literature when describing the type of learning opportunities they desire. One teacher described a combination of formal, informal and independent learning activities when asked about a preferred model for learning new technologies. She explained, "a seminar where they show you all the cool stuff for an hour…play with it, and (instructors) walk around and answer any questions" would be a perfect model. In this description, we hear her describe a formal mode for introduction of the technology, an independent mode for hands-on experience with this technology, and informal support.

Discussion and Implications

The emergence of information and communication technologies has extended the landscape of teacher professional learning activities for technology integration beyond

the school walls, yet it has left school-based formal PD largely untouched. Teachers now have constant access to resources and people previously unavailable, which provides them a greater degree of flexibility in terms of when they engage in professional learning activities, with whom they choose to work, and their level and style of engagement. Access to global resources can provide learning experiences in narrowly focused content areas and grade levels, as well as provide just-in-time and on-going support. Teachers in this study reported utilizing these new technological tools, and articulated how they can be an efficient and effective way to discover and better understand how to integrate emerging technologies into their instruction. However, school processes and policies for teacher learning have largely not kept pace with this evolution and remain outdated: school divisions still primarily focus on facilitating and supporting teacher learning about technology through formal learning activities even as current teacher practices, utilizing emerging technologies, demonstrate the affordances of informal and independent learning activities. While research on effective practices for teacher learning has been available for decades, schools, possibly constrained by district and state level policies, continue to primarily only recognize traditional face-to-face learning activities, college coursework and other formal learning opportunities for teacher recertification requirements.

Teachers in this study recognized that creating formal PD that is appropriately differentiated for teachers is difficult and to compensate for when this doesn't occur, they fill in the gaps with informal and independent professional learning activities. The range of expertise in technology use, the instructional nuances between grade levels and content areas, the differences in teaching styles, and the rapid evolution of technology make it difficult for organizations to develop effective formal learning opportunities about

technology integration that are appropriate for all of its teachers. Teachers in this study articulated how they utilized informal and independent professional learning activities to partially address many of these barriers. School leaders must also work within the constraints of district and state level policies. State level recertification requirements and compensation models for teacher engagement in independent and informal professional learning activities should also be re-imagined, allowing for the benefits of modern technology to be considered, and removing the constraint of accounting for teacher PD solely through seat-time and university course work. Further research in this area of educational policy will help inform forward progress in this area.

As mentioned in the results section, the school in which the teachers in this study were located was beginning to consider how to combine learning modes to better facilitate professional learning activities for technology integration. Primarily this was done through providing compensation for independent learning activities during the summer break. Two of the teachers in this study extended this activity into an informal collaboration and expressed positive reactions to the support provided to them from their administration. Lack of time is an often-reported barrier for teachers seeking learning opportunities for technology integration. However, as evidenced by this example, some teachers are willing to engage in professional learning activities outside of work time if this time is recognized, compensated, and relevant. This model could also be expanded to the benefit of both the teachers and the organization. By supporting these types of professional learning activities teachers may be more willing to engage in them. By providing instruction on utilizing these types of professional learning activities, teachers will become more adept in their participation, and by providing tools and policies to

document teacher learning derived from these activities, knowledge can be better disseminated throughout the organization and archived for subsequent learning activities.

School leaders should not only recognize and provide support for independent and informal professional learning activities, but also should incentivize teachers to engage in these activities and develop ways to aggregate teacher knowledge and disseminate information arising from these activities throughout their organization. Teachers currently engage in these types of learning activities despite organizational support, and therefore do not fully realize the learning potential inherent in them. As well, educational organizations miss opportunities to develop capacity within their organization and benefit from teachers' knowledge and experience. Teachers in this study reported their engagement in all three learning modes, and illustrated how they are inter-dependent. They described how ideal professional learning activities should incorporate elements of each mode. School divisions need only look to their teachers for guidance in developing a more holistic teacher-learning program. Teachers in this study reported that formal professional learning activities were often effective for initial exposure to emerging instructional technologies. They described their need for independent learning time to engage in hands-on activities, understand the technologies for themselves, and utilize their experience and creativity in developing instructional uses of the technologies. They reported informally collaborating with their colleagues to design effective instructional practices with the technologies and support each other in the implementations of the technologies in their classrooms. School leaders could support these activities through formal instruction on tools and practices which support independent and informal learning, provide time during the workday to engage in informal and independent

professional learning activities, support platforms and practices to facilitate collaborative learning, and recognize these activities through compensation and recertification requirement fulfillment.

Conclusion

While the small sample size used for this study does not allow for generalizations, it does provide an insightful illustration of the professional learning activities of four middle school science teachers in a single school for technology integration. The unique research design promoted accurate recollections of teachers' professional learning activities that were parlayed into gathering their perspectives on the menu of options available to them for their professional learning activities. Through their voices we were provided a glimpse into the barriers they encountered and the benefits they perceived from various learning opportunities. This insight should be useful for schools and districts as they develop effective teacher learning opportunities for integrating technology. While findings from the survey data indicate informal learning activities were the most frequently reported, caution should be taken in interpreting these results. Activities categorized as informal in our survey also had the greatest number of possible choices. While this surely contributed to the skewed results towards informal activities, it also illustrated the greater number of informal options available to teachers. The survey results in this study were primarily used to develop the qualitative interview protocols. By utilizing quantitative survey data, interview protocols were developed to address specific areas of interest as opposed to one standard protocol. This allowed for a differentiated line of questioning by time and by teacher. This method allowed for focused questioning, and provided teachers with data to react to and expand on, yet it

meant that perhaps differences in teachers' perspectives about a common issue were not brought out.

This study adds to the literature base on science teacher learning of technology integration and addresses several existing gaps. By looking holistically at teacher learning activities, as opposed to focusing on solely formal, informal, or independent learning modes the interdependence between the modes and the synergies created between the modes become evident. Just as teachers engage in all three learning modes, research in this area must also consider all three. While this study suggests that further research in the areas of informal and independent science teacher learning activities for technology integration is needed, research into hybrid models combining modes and the synergies created by supporting all three modes is warranted as well. Due to the effect emerging technologies have had on the landscape of teacher learning in this area, we recommend that future research in this area should consider the resources and expertise now available to science teachers, as well as the new ways and means these teachers can engage in this global learning environment. Of course as greater insight is gained into how teachers' different learning activities all work together, future research should also contribute to how the professional development activities available to teachers impact their learning processes, and most importantly contribute to their knowledge construction.

To more holistically support science teacher learning of technology integration, teachers, principals, district leaders, and educational policy decision makers must first acknowledge and understand the nature of informal and independent teacher learning activities. This recognition is noticeably absent even from teacher's perspectives, as evidenced in this study from the low number of independent learning activities reported

on the surveys. Although revealed in the qualitative interviews, teachers themselves did not recognize the amount of independent learning activities they engaged in when asked about these activities on the surveys. One teacher in the study provided a hypothesis for this: “I don’t think teachers even realize how much they do independently”, and later stated, “its hard to dig down and find it, to get them to understand they do a lot”. Another teacher revealed that when these activities go un-recognized by school leaders, teachers themselves stop recognizing them.

Between more focused efforts by researchers to understand how teachers combine these three learning modes and increased efforts by leaders to support the synergies among them, the holistic approach we advocate here can be shaped for maximum impact. Instructional technology designers and developers can and should bolster this vision with Internet tools and applications that will support researchers, leaders, and teachers, and bring a holistic model of teacher learning to fruition.

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Table 1

Teacher Activities Reported on Survey Categorized by Learning Mode

Learning Mode	Activity from Survey
Formal	School sponsored PD
	Teach a lesson incorporating CANLEAD materials
	Discussed lesson plans in meeting
	Discussed student work products in meeting
	Discussed topics and technologies in meeting
	Review CANLEAD content pages
	Plan a lesson incorporating CANLEAD materials
Informal	Discussion with peers about CANLEAD materials
	Discuss topics and possible technologies in person
	Discuss lesson plans in person
	Discuss student work products in person
	Discuss topics and possible technologies in an online environment other than CANLEAD
	Discuss lesson plans in an online environment other than CANLEAD
	Discuss student work products an online environment other than CANLEAD
	Discuss topics and possible technologies in an other environment
	Discuss lesson plans in in an other environment
	Discuss student work products in an other environment
	Share lesson plans by email
	Share lesson plans by hard copy, print out
	Share lesson plans through Blackboard
	Share lesson plans through other means
	Share student work by email
	Share student work by hard copy, print out
	Share student work through Blackboard
	Share student work through other means
	Share external resources by email
	Share external resources by hard copy, print out
	Share external resources through Blackboard
	Share external resources through other means
	Share lessons with peers

Learning Mode	Activity from Survey
	Discuss lessons with peers
	Share student work done with peers
	Discuss student work with peers
Independent	Independent PD
	Planned a lesson with independently researched technology
	Taught a lesson with independently researched technology
	Perform independent research on formal technologies
	Perform independent research on independent technologies

Table 2

Code Scheme

1. Modes of Learning
1.1. Formal
1.2. Informal
1.3. Independent
1.4. Synergistic relationship between formal and informal modes
1.5. Synergistic relationship between formal and independent modes
1.6. Synergistic relationship between informal and independent modes
1.7. Synergistic relationship between all three modes
2. Community Learning
2.1. Community learning activities within grade level
2.2. Community learning activities within department
2.3. Community learning activities within school
2.4. Community learning activities within districts
2.5. Community learning activities outside of district

Appendix 1. Weekly Teacher Survey

Page #1
In the past week which of the following topics were you working on?

Science

Chemical Equations
Chemical Reactions
Convection, Conduction, Radiation
Elements and Compounds
Gravity
Importance of Water and Conserving Resources
Protons, Neutrons, and Electrons
Phase Changes
Physical v. Chemical Change
Potential, Kinetic, and Thermal Energy
Properties of Air and Atmosphere: Pressure, Temperature, Humidity
Properties of Water
Renewable and Non-Renewable Energy Resources
Seasons
Solar system
Weather
Cells
Linnaeus Classification Characteristics
Photosynthesis
Interactions Among Members in a Population
Biotic and Abiotic Factors
Population Size
Ecosystem Dynamics and Human Activity
Genetics
Physical and Chemical Properties of Matter
Elements, Compounds, Mixtures, Acids, Bases, and Salts
Models of the Atom/Atomic Structure
Organization of the Periodic Table
Physical and Chemical Changes/Nuclear Reactions
Energy
Temperature Scales, Heat, and Thermal Energy Transfer
Sound Waves
Transverse Waves
Work, Force, and Motion
Electricity and Magnetism
I did not do any Science topics.
Other:

Math

Absolute Value
Exponents & Scientific Notation

Fractions, Decimals, & Percents
Integers
Ratios and Proportions
Real Number Relationships
Squares & Square Roots
Angles & Polygons
Pythagorean Theorem
Circles
Transformations
3-D Figures
Algebraic Properties
Expressions
Solving Equations
Inequalities
Functional Relationships
Graphing Linear Equations
Sequences
Statistics: Central Tendency
Statistics: Data Collection & Analysis with Graph Creation
Probability
I did not do any Math topics.
Other:

Page #2

Which of the following technologies did you use in your topics? Select all that apply.

Spreadsheets
Simulations
Games
Inquiry Learning Environments (WISE)
Probeware
Digital Images
Dynamic Geometry Software
Virtual Manipulatives
Graphing Calculators
Other:

Page #3

	I did not do this.		I read through the topic page and looked at the resources listed there.		I followed the link to a resource for the topic and opened its associated files or examples.		(All of level 4 plus) I also looked for additional technology to use with this topic.
Did you review any topics on the CANLEAD website?	0	1	2	3	4	5	6
Did you discuss the teaching of these topics with the suggested CANLEAD related resources?	0	1	2	3	4	5	6
Did you plan a lesson that used a CANLEAD related technology?	0	1	2	3	4	5	6
Did you teach the lesson?	0	1	2	3	4	5	6
Did you share your lesson with colleagues?	0	1	2	3	4	5	6
Did you discuss your lesson with your colleagues?	0	1	2	3	4	5	6
Did you share with colleagues student work made with this technology?	0	1	2	3	4	5	6
Did you discuss how students work product gives insight into student learning and/or the effectiveness of the lesson?	0	1	2	3	4	5	6

Page #4

For the following questions please select all that apply. Indicate all means of communication, besides your activity within the CANLEAD website. If you completed any of these tasks within the CANLEAD website you don't need to write that as a response.

In the past week, how did you participate in discussion with colleagues about TOPICS AND POSSIBLE TECHNOLOGIES?

In person with 1 or more colleague(s)
In a meeting
In an online environment other than CANLEAD
Other:
I did not do this

In the past week, how did you participate in discussion with colleagues about LESSON PLANS?

In person with 1 or more colleague(s)
In a meeting
In an online environment other than CANLEAD
Other:
I did not do this.

In the past week, how did you participate in discussion with colleagues about STUDENT WORK PRODUCTS?

In person with 1 or more colleague(s)
In a meeting
In an online environment other than CANLEAD
Other:
I did not do this

In the past week, how did you share LESSON PLAN(S) with colleagues?

By Email
By hard copy, printed out
Blackboard
Other:
I did not do this

In the past week, how did you share STUDENT WORK with colleagues?

By Email
By hard copy, printed out
Blackboard
Other:
I did not do this

In the past week, how did you share EXTERNAL RESOURCES with colleagues?

- By Email
- By hard copy, printed out
- Blackboard
- Other:
- I did not do this

Page #5

School Sponsored PD outside of CANLEAD

Have you participated in any school sponsored PD outside of CANLEAD that provided training related to CANLEAD technologies?

- Yes
- No

If you replied Yes above please briefly describe your PD experience, including type of PD and specific names or locations:

Did you make use of this PD experience in your CANLEAD related work?

- Yes
- No

Page #6

Independent PD outside of CANLEAD

Have you participated in any independent PD (conferences, online webinars, etc) outside of CANLEAD that provided training related to CANLEAD technologies?

- Yes
- No

If you replied Yes above please briefly describe your PD experience, including type of PD and specific names or locations:

Did you make use of this PD experience in your CANLEAD related work?

- Yes
- No

Page #7

You marked Other for the technology you did this week. Please indicate any of the following activities you performed this week regarding non-CANLEAD technologies Check all that apply:

- Perform independent research
- Plan a lesson
- Taught a lesson

Page #8

If you have not investigated or used any of the CANLEAD related technologies; what barriers or issues did you encounter?