STEM Teachers in Professional Learning Communities: A Knowledge Synthesis

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Introduction

This report describes a comprehensive knowledge synthesis of professional learning communities (PLCs) and their impact on science, technology, engineering, and mathematics (STEM) teaching and learning in K-12 education. It is supported by NSF grant DRL 0822013, awarded in August, 2008 to the National Commission on Teaching and America's Future (NCTAF) and WestEd. This report is organized around the following sections: Background, Overview of Key Findings, Methodology, Results, and Discussion and Implications.

Background

Three overarching questions guide this secondary analysis:

- What do we know about PLCs involving STEM teachers?
- How robust is the research base about PLCs involving STEM teachers?
- What further research and development are needed?

The study's analysis focuses on various configurations of STEM teachers in PLCs, the purposes of these PLCs, approaches to conducting PLCs, including online venues, and internal and substantive expertise made available to PLCs. The study's guiding questions examine the current knowledge about the relationship of these and other PLC attributes to effects on the following: teachers' content knowledge and pedagogical content knowledge (PCK), implemented instructional practices, their students' achievement, and teachers' job satisfaction and retention.

The partnership of NCTAF and WestEd researchers blends two kinds of expertise that guided the study: NCTAF's reputation as a national nonprofit, nonpartisan research, advocacy and action organization, well regarded for its focus on teaching quality; and WestEd's strong track record for research.

With the publication of *What Matters Most: Teaching for America's Future* (NCTAF, 1996), NCTAF defined preparing, supporting and promoting quality teaching as the critical path to educational improvement. This report was followed by the creation of a network of state partnerships, now numbering 27, committed to addressing the goals set forth in that agenda for improving American education. NCTAF has continued to publish research on the topic, focusing on teacher turnover and its costs (*No Dream Denied*, 2003; *The Cost of Teacher Turnover*, 2007). In looking at the contributing causes of teacher turnover and actions being taken to address this problem, NCTAF began to focus on the potential of building strong learning communities (*Induction into Learning Communities*, 2005; *Team Up for 21st Century Teaching and Learning*, 2010).

The retention and support of high quality STEM teachers have become a NCTAF priority. With NSF support, NCTAF held two invitational workshops on STEM teacher turnover and retention at the Wingspread Conference Center in Racine, Wisconsin. The first workshop, "Scope and Consequences of STEM Teacher Turnover," held in the fall of 2006, brought together researchers and STEM practitioners to discuss Richard Ingersoll's data on STEM teacher turnover (Ingersoll & Perda, 2006). That analysis of the National Center for Education Statistics Schools and Staffing Survey indicates that, although some teaching fields (i.e., elementary education, English and social studies) have a surplus of teachers that is sufficient to cover both retirement and pre-retirement departures, the picture is dramatically different in STEM disciplines, where the supply is barely sufficient to cover normal retirements – leaving no slack to cover high rates of pre-retirement departures. Consequently, pre-retirement STEM teacher turnover and attrition are having a negative impact on the teaching workforce and student learning in school districts across the country.

NCTAF hosted a follow-up NSF-sponsored meeting in the fall of 2007, also at Wingspread, on the topic "Induction of Math and Science Teachers into Professional Learning Communities." This meeting brought together a second group of STEM researchers and practitioners to discuss invited papers on the induction of new STEM teachers in the U.S. and overseas (Britton, 2007); a description of several models of PLCs for new secondary science teachers (Luft, 2007); and impacts of new teacher induction models on elementary student assessments in literacy and mathematics (Fletcher, Villar & Strong, 2007). The major recommendation from this conference was the need for a comprehensive synthesis of existing research as well as new research on PLCs and their impacts (on teacher performance, retention and student learning), especially in mathematics and science (http://www.nctaf.org/resources/events/STEMWingspreadConference.htm).

This recommendation led NCTAF to collaborate with Britton and his colleagues at WestEd in developing the proposal for the NSF Knowledge Synthesis described in this report.

WestEd brings to the project a strong background as a nationally renowned educational research and service organization. WestEd conducts research, and research and development (R&D) programs, projects, and evaluations; provides training and technical assistance; and works with policymakers and practitioners at state and local levels. Over the past 41 years, WestEd and its two predecessors, Far West Laboratory for Educational Research and Development (FWL) and Southwest Regional Laboratory (SWRL), have carried out nearly 2,000 successful projects. Britton's research in induction in the U.S. and overseas (Britton, Paine, Pimm & Raizen, 2003) and a recent NSF-supported Knowledge Synthesis on Induction for STEM Teachers (Britton, McCarthy & Ringstaff, 2010) brought important research expertise and experience in both the topic area and the knowledge synthesis process.

This study is aimed at both the research community and the practice community, but also has value for the policy community. The research community will benefit from a deeper understanding of where knowledge gaps exist in the research base, as well as hypotheses for new or further investigation, and a suggested agenda for future research (see section *What does the Research Say?*). The practitioner community will benefit from the discussion of what is known about different models, their impacts, implementation issues and generalizability – along with what gaps are present with respect to these topics (See sections *What do the Professional Education Organizations Advise?*, *Guidance from an Online Panel of Researchers and Practitioners* and *Discussion of Models*). The policy community can use this information as they consider professional development plans and expenditures, staffing models, and school organizational design and use of resources.

What do we Mean by PLCs and Why is it Important to Study Them?

The concept of Professional Learning Communities became popular in the 1990s, borrowing from the "learning organization" in business described by Senge in *The Fifth Discipline*. Senge's learning organizations are places "where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together" (Senge, 1990, p. 3). Lave and Wenger studied "communities of practice" among adults, studying how people in organizations share information, collaborate and learn from one another (Lave & Wenger, 1991; Wenger, 1998). Workers tackle new tasks through "cognitive apprenticeships" in which their learning is supported by knowledgeable others who can model, mentor and guide their understanding where learning is situated in authentic work (Lave & Wenger, 1991; Brown, Collins & Duguid, 1989; Wenger, McDermott & Snyder, 2002).

This framework for learning made sense to educators seeking to reform schools in the aftermath of the landmark report *A Nation at Risk* (National Commission on Excellence in Education, 1983). The term "learning communities" became popularized in educational journals and models began to be adopted in some schools and districts (Hord, 1997). Education articles defined critical elements and their impediments (Kruse, Seashore Louis & Bryk, 1994). DuFour and Eaker define learning communities as having a shared mission, vision and values; typically involving collective inquiry, collaborative teams, action orientation/experimentation, continuous improvement and a results orientation that focuses on student learning (DuFour & Eaker, 1998; DuFour, 2001; DuFour, 2004). Hord's framework of "Five Dimensions" of PLCs is also widely cited; these are 1) supportive, shared leadership; 2) collaborative learning with a student needs focus; 3) shared vision and values focused on student learning; 4) supportive structural and interpersonal conditions; and 5) shared practice (Hord, 1997; Hord, 2008). The concept of shared practice reflects the importance of the "deprivitization practice" and focusing on collaboration (Newmann & Associates, 1996).

A number of education researchers (Fullan 2002; Cibulka & Nakayama, 2002; Schmoker, 2004) have described learning communities in the context of school reform more broadly. Others focus on specific challenges associated with the creation and implementation of such communities (Levine, Laufgraben & Shapiro, 2004; Joyce, 2004) and as vehicles for teacher learning and improved professional development (Darling Hammond, Wei, et al., 2009; Darling-Hammond & McLaughlin, 1995) More recently, literature reviews have begun to look at the impacts of PLCs on teacher learning and on student achievement (Vescio, Ross & Adams, 2008; Carroll, Doerr & Fulton, 2010). These studies review the work of PLCs both in the U.S. and overseas. However, their perspective is of PLCs writ broadly, not focusing specifically on impacts of science, technology, engineering or math (STEM) teachers.

This is not to say that there has not been research on PLCs for STEM teachers; only that it is time for a synthesis that focuses specifically on this subset of research. This is especially important given that the National Science Foundation has, in the last few years, funded a growing number of development and/or research projects on STEM Professional Learning Communities. However, there has been no synthesis of this recent work, making the synthesis of knowledge described here especially timely and important.

Overview of Key Findings

Before highlighting the findings, we review three aspects of our study that are important for understanding these findings. First, the charge in this study examined professional learning communities (PLCs) whose membership and focus was exclusively on one or more subjects of science, technology, engineering and/or mathematics (STEM); or, if other subjects also were included, the STEM aspects were explicitly addressed. Therefore, **we did not review the PLC literature as a whole**.

However, we raised the question "Are STEM PLCs a different phenomenon?" with both our online panel and advisory board, since many of these individuals also have general experience with PLCs. They indicated that **what we found for STEM teaching is generally confirmed by their experience with the PLC literature at large**. Thus, our report generally contextualizes the PLC discussion specifically for STEM rather than making a case that STEM PLCs are a very different enterprise; but there are a few aspects that do seem unique to STEM PLCs. A valuable area for future analysis would be a formal explicit comparison of PLCs in STEM fields versus PLCs more broadly.

Second, while the topic of Professional Learning Communities is under widespread, extensive discussion among both researchers and practitioners, the range of PLC definitions is quite wide, to put it mildly. Our task was not to create an official definition of a PLC. Nonetheless, we maintain that it is important for the field that **each of the components in the term "Professional Learning Community" should be fulfilled in order to regard some activity as a PLC: *professional* – engaging educators in the development of their professional practice; *learning* – focused on both the learning of the educators and the learning of their students; and *community* – which requires common vision, goals, purpose, and a shared sense of trust as well as collaborative work.** Beyond this stance, our definition of PLCs for this study generally was meant to be inclusive rather than restrictive: involving three or more teachers, including a STEM focus, and being a sustained enterprise rather than a one-shot or very limited-time endeavor; generally, our STEM focus precluded consideration of enterprises where whole schools are operating as PLCs.

Third, **this "knowledge synthesis" was enhanced by beginning with a traditional literature review but expanding it to include additional sources of knowledge that are important for understanding this topic at this moment in time**. Thus our sources also include published expert advice and opinions/policy, published descriptions of models for STEM PLCs and their "lessons learned," and reactions and advice from a panel of people having expertise on designing and leading STEM PLCs. Because much of the work of PLCs in STEM is relatively recent (e.g., research reports are only now being produced as a result of Math Science Partnerships funded by NSF in recent years), the volume of empirical research studies is growing quickly each year but as of now it is evolving rather than mature. While our other knowledge sources may not meet the "gold standard" of empirical research, we found that they generally were consistent with findings emerging from the empirical studies and were important for elaborating them.

We group the most notable results of our knowledge synthesis by addressing four questions:

1. **What do We Know about STEM PLCs**? What are the findings? Some findings cut across all the kinds of knowledge sources that we amassed, while others are more specific to particular knowledge sources used in our project.

2. **How Well do We Know it?** How strong is the knowledge that we found?

3. **What is the Source of this Knowledge?** Describes the landscape of available knowledge.

4. **What Else Might We Want to Know?** What are the most notable gaps in the available knowledge

What Do We Know about STEM PLCs?

They were universally recommended

- Published comments or policy statements about STEM PLCs support their use to an amazing extent. Unlike most topics in education, there was no opposition; however, there were important cautions about being clear and substantial rather than superficial in defining and implementing them. All other knowledge sources also recommended their use (e.g., the conclusion sections of research articles).

There are key elements to consider in designing STEM PLCs

- In designing STEM PLCs, close attention needs to be paid to many aspects related to time and pacing. There can be issues in how to evolve over time a stronger and stronger group focus on mathematics and science content knowledge as well as on pedagogical content knowledge (PCK), since public discussion of them might be very foreign and threatening given our historical practice of teaching in isolation. The relationship between specific desired PLC purposes and the available conditions for meeting them must be wisely factored into deciding how much time to meet and how often, and what's happening during the times in-between.
- Comprising PLCs with teachers from multiple subjects (even limited to mathematics and science) can limit the depth or effectiveness of work on content knowledge or PCK.
- Having protocols for STEM PLC group functioning is important, as is building in protocols for examining students' work. However, design and use of protocols must be carefully considered and monitored (e.g., the protocol can become the end instead of the means).
- Having facilitation, administrator support and trust-building are crucial. Regarding facilitation, there are many kinds but all of them require some professional development because facilitating adult learning is different than facilitating student learning.

We found positive changes in STEM teachers.

- Participation in PLCs can successfully engage teachers in discussion about content knowledge or knowledge about how to teach it (pedagogical content knowledge or PCK), positively impacting their understanding of or preparedness to teach content, or attitudes toward teaching methods.
- Participation in PLCs increased teachers' deliberation about students' mathematics or science thinking.

We found positive changes in STEM teachers' instruction.

- Participating teachers' practices often become more "reform-oriented" (although this term was often imprecisely defined and/or the reform practices were not clearly defined).
- Studies reported increased teacher instructional attention to students' reasoning and understanding, and use of more diverse modes of engaging student problem-solving.

We found a small number of studies showing positive effects on mathematics student learning and achievement.

- Only a few studies were available, and all of them investigated student impacts in mathematics; this is likely, in part, because there commonly are more assessment data available in mathematics.
- Overall, this small set of studies gives some existence proof that teacher participation in a mathematics PLC can lead to an enhancement in what their students learn. The case cannot yet be made from these studies that sufficient evidence exists to clearly link results on formal student assessments to teacher participation in PLCs, but the positive trend is noteworthy. The PLC literature at large (versus specific to STEM PLCs) that examines the relationship between student achievement and teacher PLCs is similarly emergent rather than definitive (Vescio, Ross & Adams, 2008).

How Well Do We Know It?

- More often than not, we were unable to glean exactly what the PLC was. They are called many things; we had to use 35 terms (plus their variants, e.g., both "lesson study," and "lesson studies") to thoroughly capture relevant knowledge.
- On top of the nomenclatural problem, articles often did not precisely describe the "it," e.g., whether the PLC was mandatory or voluntary, how often and long participants met, whether there were facilitators and/or their identity/role, etc.

- Individual research studies were found to be weak during our analysis, but, collectively, research is building a supportive case that STEM PLCs have effects valued by STEM educators and policymakers. Research articles did not fare well in a 4-8-hour inspection (per article) of their methodological rigor by a doctoral-level analyst. However, it is important to note that such inspections of research in other topics in education often yield similar weaknesses. Thus the problem is not unique to research on PLCs.

What is the Source of Our Knowledge?

- There are many published policy statements or recommendations about PLCs that are specific to STEM education. There also is a solid base of published expert advice and some descriptions of STEM PLC models (published either in description-only articles or research articles that included "lessons learned" about STEM PLC design or execution). More empirical studies are needed (research designed to investigate specific research questions); two-thirds of the identified studies were published in the last five years.
- The available knowledge is fairly rich for understanding issues in designing STEM PLCs as well as issues and principles for carrying them out. But more precise or fine-grained understanding is needed on specifics of carrying out various PLC configurations for specific purposes.
- Knowledge about understanding the effects of PLCs is uneven. Claims seem moderately substantiated that STEM PLCs can contribute to changes in teacher beliefs or changing teachers' knowledge of STEM content or content pedagogical knowledge (PCK). More evidence of changes in students' learning or achievement clearly is needed.
- We found a great deal more information about PLCs in mathematics than in science. Not much is published about PLCs specific to technology education or pre-engineering (the "T" and "E" of STEM), which mirrors the situation that these content disciplines are rarer as separate school subjects in the U.S. education system than mathematics or science. Therefore, although we use the current pervasive acronym "STEM" throughout this report, in reality we are speaking primarily about mathematics and, to a lesser extent, science.
- Our panel of experts, having direct and substantial experience with designing and implementing STEM PLCs and entire STEM PLC programs, confirmed that they had been successful in obtaining the kinds of results cited above that arose from the research studies. Furthermore, they had personally obtained and witnessed such effects of PLCs elsewhere, even when implemented in very challenging schools and school districts.

What Else Might We Want to Know?

- We need to know more about STEM PLCs that are naturally-occurring in the field. Existing published knowledge to date (research, advice and models) overwhelmingly focuses on specific PLC projects created for the purposes of a research study, in contrast to seeking out naturally occurring STEM PLCs for study wherever they are found. Many school districts likely are collecting evidence of the effects of PLCs (evaluations, if not research) which could be assembled for analysis. National independent case studies along with collection and analysis of such local existing evidence might be quite valuable. However, job incentives for university-based researchers favor generation of primary knowledge/theory over such applied investigations, and external funders do not commonly support secondary analyses.

- We need to know more about how STEM PLC-like experiences can play out during teacher preparation as well as in online settings. We included these areas in our project's charge, but found only eight preservice and seven online research studies. At the preservice level, experiences were described in STEM methods courses or during student teaching or other field experiences. Many of the articles about online experiences also were about preservice teaching. This report does discuss the identified articles later, but these thin sets of studies did not yield an overall pattern of results warranting inclusion in the current overview of findings.

Methodology

Framework and Guiding Questions

The Knowledge Synthesis looked at PLCs involving STEM teachers across grades K-12 and in teacher preparation. We used as a threshold a minimum of three teachers; collaborative work by two teachers was not included (e.g., teacher pairing of a single mentor and new teacher only for purposes of induction support are not within our definition of a Professional Learning Community). While research on PLCs that are exclusively for teachers of science, mathematics, engineering or technology (or combinations of STEM subjects) was addressed, the synthesis also reviewed research on cross-subject PLCs where data about the experiences and effects for their participating STEM teachers is disaggregated. We reviewed the range and frequency of PLCs for STEM teachers, what is known about implementation issues around different models (i.e., online vs. face-to-face, PLCs for induction vs. those involving more experienced teachers, within or across schools, etc.), and their effects. Specific guiding questions on effects include:

1. What are the effects of STEM teacher participation in PLCs on teachers' math and science content knowledge and pedagogical content knowledge (PCK)?
2. What are the effects of STEM teacher participation in PLCs on teachers' mathematics and science instructional practice?
3. What are the effects of STEM teacher participation in PLCs on their students' mathematics and science achievement?
4. What are the effects of STEM teacher participation in PLCs on teachers' attitudes toward teaching, feelings of preparedness, professional and collegial interactions, and retention?
5. What is known about online forms of PLCs and their outcomes?

Knowledge Sources

Preliminary searches for the current proposal indicated that restricting the knowledge synthesis only to empirical and descriptive studies in peer-reviewed journals would be too incomplete to aid end users in fully understanding the issues, both because the amount of such research is currently limited, and because there is a great deal of "working knowledge" on STEM PLCs found through other sources. In order to capture this wide variety of information, we identified four kinds of knowledge for analysis and synthesis, building on the Knowledge Management and Dissemination project (KMD), conducted by WestEd in partnership with, and under the leadership of, Horizon Research and the Education Development Corporation (EDC) (Britton, Putnam & Fulton, 2009; Heck, Weiss & Miller, 2009; Weiss, Pasley, Heck & Taylor, 2009). However, based on suggestions presented by NSF reviewers and staff, we determined it would be useful to add an additional category that would explicitly attend to knowledge about models of conducting PLCs. We found a considerable body of research in this category, some with "lessons learned" but without formal research.

These five classes of knowledge that were our data sources are described below:

1. Empirical and descriptive studies published in peer-reviewed education and policy journals (e.g., *Educational Evaluation and Policy Analysis, American Educational Research Journal, Educational Policy, Science Education – Issues and Trends Section*) published since 1995 (**"Type 1" knowledge sources**).
2. Empirical and descriptive studies published (including online) in venues other than peer-reviewed journals (e.g., research funded by a state agency that is published on their website, primary studies conducted by stakeholder organizations, or secondary analyses focused on policy issues) (**"Type 2" knowledge sources**).
3. Published expert knowledge, opinion and/or advice (not research) located in periodicals or on websites and professional development trade books (e.g., *Education Week, Phi Delta Kappan*) (**"Type 3" knowledge sources**).
4. Current practice-based knowledge collected through the use of an Expert Practitioner Online Panel made up of seven practitioners who have conducted PLCs with STEM teachers (**"Type 4" knowledge source**).
5. Published descriptions of models of STEM teachers in PLCs, often with "lessons learned" but not formal research, generally derived from the Type 2 and/or 3 sources (**"Type 5" knowledge sources**).

Determination of Criteria for Inclusion and Search Terms

We determined that, for our Type 1 and 2 knowledge sources, we would review articles published since 1995. Other criteria for inclusion are:

- The studied phenomena must involve three or more classroom or preservice teachers, but the PLC could also have other kinds of participants (e.g., administrators or college faculty); excludes articles with sole focus on 2-person interactions such as team teaching and mentoring relationships.
- The studied phenomena should meet the following criteria:

  - should have a concerted focus of teachers interacting for varied purposes related to improving their teaching;
  - should be more than a short-term, one-shot experience (i.e., a week or two), although this criterion is less absolute for PLCs involving preservice teachers;
  - should not be treated in the article as one strategy among a primary focus on a broader project, such as school reform or developing a whole school community; and
  - use face-to-face activities, online modes, or both.
- The studied phenomena either (1) entirely involves mathematics and/or science teachers, or (2) extensively discusses specifics of STEM teachers' involvement, including substantial presentation of study results specific to the participating STEM teachers. While the search terms also aimed to capture communities including technology and engineering teachers, we found very little research that addressed these content areas.

The project's original search for literature in the fall of 2008 employed standard search engines to locate studies, but for several reasons had to use unusually intensive methods both for searching or screening the potential studies obtained. We found that practitioners and researchers use a very wide range of terms to label the phenomenon of teachers working together to improve their practice. For our review, we entered the terms given in Table 1 below, and variations of them, into the PsycINFO and EBSCO Education Complete search engines. While variants of "professional learning community" and "lesson study" yielded the greatest number of candidate articles, most of the other "PLC" terms also yielded some candidate studies. The search parameters also used Boolean logic to require every obtained entry to include terms related to STEM teachers.

Searches with these terms yielded approximately 20,000 hits, which created challenges that necessitated an intensive screening process. Through using the EBSCO feature "sort by relevance" (i.e., to the search terms), we were able to limit formal inspection to the first 750 entries. However, there was great inconsistency among these in writers' use of the widely-varying terms for PLC-like activity in Table 1, with any individual term having multiple meanings employed across the article set and often conceptually overlapping with the referent phenomenon associated with other terms. Therefore, these terms alone found in article titles and abstracts frequently were very inadequate for determining whether the objects of study were PLC activities of interest to the project.

Any article wherein study subjects exclusively were mathematics or science teachers was of immediate interest, or, at the elementary level, ones examining only mathematics and/or science teaching. However, article titles and abstracts were frequently inadequate to determine whether a sufficient proportion of study subjects were mathematics or science teachers, and/or whether articles results and discussion gave sufficient attention to subject-specific issues to warrant project attention.

Table 1. Search Terms Used for "Professional Learning Communities" and "STEM Teachers"

Terms for PLC
professional learning community
learning communities
critical friends
critical friends group
networks
collaboration
teacher collaboration
lesson study
lesson study group
study group
teacher network
teaching network
sharing best practice
shared practice
collaboration time
professional development
colleague
professional colleagues
grade level collaboration
subject level collaboration
collective inquiry
collaborative teams
collaborative learning
collaborative inquiry
group lesson planning
joint lesson planning
professional teaching teams
district learning teams
facilitated learning community
supported learning community
online collaborative tools
online sharing
online collaboration
internet learning
networking

Terms for STEM Teachers
science teacher
chemistry teacher
earth science teacher
mathematics teacher
physics teacher
science
environmental science
engineering
computer science
physics
chemistry
biology
astronomy
integrated science
earth science
math
mathematics
STEM
algebra
geometry
calculus
pre-algebra
integrated math
technology
engineering

A "refresh" search was conducted in July 2010 to update the pool of articles with the most recent literature. Databases included in this search are EBSCO's Academic Search Complete, ERIC, Education Search Complete and PsycINFO databases. The same search strategy as the 2008 search was used, but the results were limited to articles published from January 2009 to July

2010. Since the hits returned from this search were relatively small in number compared to the 20,000 hits of the first search, a researcher screened each abstract found in this search and compiled 33 articles for a more intensive review. Of those 33, 7 articles are identified as Type 1, 3 articles as Type 2, 1 article as Type 3 and 4 articles as Type 5. Inspection of full articles revealed that 18 of these were not sufficiently relevant to the study's STEM and PLC foci to be included.

Preliminary Screening and Review of Articles

Whenever an abstract was inadequate for making a judgment regarding either the "PLC" or math/science criterion, full articles had to be inspected. An indicator of the necessity of this intensive search and screen process is that more than half of the articles obtained to date were in periodicals outside of those focused on mathematics and/or science education; therefore, solely relying on an issue by issue inspection of STEM education research journals would not have yielded the full body of STEM-specific PLC research on this topic, which is an alternative primary search strategy described in some published literature reviews in STEM education.

As of July 2010 we selected for review 30 Type 1 articles – elaborated empirical research studies published since 1995 having sufficient methods descriptions to permit an intensive methodological inspection (these were mostly articles in peer-reviewed journals for primary research or dissertations) – and 20 Type 2 articles of non-empirical research (e.g., theory building) or empirical research reports having less specified method sections, including both journal articles and recent conference presentations.

Standards of Evidence Reviews

Over the last decade, there have been increasingly frequent and more urgent calls for enhancing the rigor of educational research and its reporting. Drawing on the research methods typically found in doctoral level texts and with the input and review of an advisory panel of research methodologists, researchers and reform leaders, an earlier Horizon Research and EDC project developed a set of 31 standards of evidence (SoE) for empirical research. In this project, we proposed applying the SoE review for our Type 1 research articles. The SoE and the process for applying them result in a careful review of the claims of individual studies and provide ratings based on specific indicators, operationalized for different qualitative and quantitative research methodologies, and narrative justifications for these ratings in six areas: adequate documentation, internal validity, analytic precision, generalizability/external validity determination, overall fit and warrants for claims.

SoE analysis has been completed of the methodological rigor of the project's 30 Type 1 articles (i.e., peer-reviewed, empirical research studies). This analysis consists of an intensive 4-8-hour, PhD-level analyst inspection of each study against the 31 standards of evidence for study design, execution and reporting (see Appendix D for discussion of SoE criteria).

Screening Published Expert Knowledge and Advice

In order to ensure breadth of opinion regarding STEM professional learning communities, we developed a list of major professional organizations and other education resources for STEM teaching and learning. (Appendix E) We sought out groups that are well respected national advocacy organizations (not for profit), and looked at those with a specific focus on STEM as well as those with a broad education reach that includes STEM along with other fields. Forty organizations' websites were searched for white papers, policy statements, official positions and research on professional learning communities among STEM teachers. Publications on their websites were searched for this information as well as periodicals/journals from these organizations for the past two years.

We began by searching the science education and math education organizations (e.g., NSF, National Science Teachers Association, National Council of Teachers of Mathematics, STEM Education Coalition), and then went on to search broad education and research groups (e.g., Association for Supervision and Curriculum Development, SRI International, National Staff Development Council, Council of Chief State School Officers). We looked for mission statements or policy positions regarding professional learning communities, as well as indicators of general support for PLCs in their work, as reflected on the organization website. As we searched we found that several organizations had created their own learning communities (often online) or had papers or books which laid out a model for implementing learning communities.

In addition, we searched two well-respected mainstream education publications (*Phi Delta Kappan* and *Education Week*). Because of the wide reach and impact of these publications, we searched them for any articles on PLCs in the past two years to ensure we capture any recent articles that may not have surfaced in the general search.

We identified 74 examples of published expert advice that were included in our analysis. Studies were broken into:

- Organization advocacy: policy and support statements, implementation models and organization-based PLCs from education organizations.
- Leading education periodical articles: Articles from two of the largest education publications, *Education Week* and *Phi Delta Kappan*, on professional learning communities.
- Articles from other relevant publications: reviews, descriptions or advocacy articles about PLCs written by researchers but not focused on a specific research project.

A "refresh" of the search process was conducted in August 2010 using the same criteria, yielding eight new examples since June 2009. Table 2 summarizes the knowledge sources by type and their characteristics. A full description of the methodology is found in Appendix D.

Table 2. Knowledge Sources by Type

Knowledge Type	Source	Number of Items	Characteristics of Knowledge Source
Type 1	elaborated **empirical research** studies since 1995, mostly articles in peer-reviewed journals for primary research, or dissertations	25 studies that each received SoE review	(For Types 1 and 2 combined): 78% qualitative only 85% focused on inservice 18% involved online components Fairly evenly distributed across elementary, middle and high school
Type 2	**empirical studies**	22 studies	

	reported without details of methods; and non-empirical studies (e.g., theory building)		2x as many in mathematics as in science 2/3 published in the last five years; only 2 studies published before 2000 Few compare different PLC modes Greatest number examined teacher experiences with/reactions to the PLC model Only a few examined changes in student outcomes Limited number of studies of online PLCs Limited number of studies of preservice PLCs
Type 3	**published expert knowledge and advice** located in periodicals or on websites; professional development trade books; advice about PLCs on Web pages (see Table 7)	40 sites of organizations searched as well as articles in *Ed Week* and *Phi Delta Kappan*	77 examples, of which greatest percentage (46%) were support statements Most common other types were were policy or position statements (22%); and news articles (15%). There were also a limited number of implementation models (9%) and organization created (9%) PLCs.
Type 4	**panel of experts**	3 rounds of questions in online survey mode Each set of questions followed by a 2-hour webinar discussion	7 practitioners and researchers (see Appendix C) Questions dealt with: • Definition of PLC • Differences between STEM PLCs and PLCs in other content areas • Key factors for effective PLCs • Minimum threshold for effective PLCs • PLCs vs. “regular” Professional Development • Role of facilitator

			• School leadership roles and impacts • Voluntary vs. mandatory PLCs • Role of the Internet
Type 5	**published descriptions of models** (sometimes with "lessons learned" but without formal research)	22 articles	Similar to characteristics of Types 1 and 2 But more evenly balanced between math (11) and science (8) or both (3)

What Does the Research Say? (Types 1 & 2 Knowledge Sources)

We first report the part of our analysis that is standard for a knowledge synthesis – a review of the research literature. This includes synthesizing findings both from empirical studies that contain some detailed description of study methods – i.e., "Type 1" sources of knowledge – as well as empirical studies presented in conference papers or published in venues that do not require substantial descriptions of the methods, or other kinds of research (e.g., theory building) – i.e., "Type 2" knowledge.

We make this distinction among research articles because this knowledge synthesis differs from typical literature reviews in an important way: for articles wherein the research was an empirical study and a sufficient description of the research methods was provided (Type 1), we meticulously analyzed the studies' methodological rigor as well as synthesizing their findings.

What Are the Characteristics of Research that Currently Exists?

There are notable patterns among the identified studies in Types 1 and 2:

- they are mostly qualitative only (78%);
- they are most often focused on inservice (85%);
- few involve online components (18%);
- they are fairly evenly distributed among levels of schooling as the focus (elementary, middle and high school);
- there are twice as many studies in mathematics education as in science education;
- they are all quite recent, with about two thirds of the studies published in the last five years and only two studies published before 2000;
- few articles compare different PLC modes;
- the greatest number of studies examined teacher experiences with/reactions to the PLC model; and
- only in a few instances did the study design or conditions permit examination of changes in student outcomes.

What Kinds of PLCs Were Studied?

What was the “it” in the research studies on STEM PLCs? Although it may seem trivial to allot report space to such basic information, for a knowledge synthesis on this particular topic, describing the investigated phenomenon is fairly important because there is great confusion in the literature and in dialogue among practitioners when discussing “PLCs.” We already noted the host of terms employed in naming them. Furthermore, there also was wide variety in the phenomena being investigated beneath the surface of the names.

If nothing else, the information in this section will be helpful whenever someone is conducting or studying a specific kind of STEM PLC and trying to determine to what extant research articles studied phenomenon that were similar to the one of interest. The following set of tables loosely categorizes the investigated PLC phenomena:

- Table 2 categorizes studied PLCs that were entirely or predominantly **face-to-face** interactions for inservice teachers. The majority of research studies focused on such PLCs.
- Table 3 categorizes **online** PLC experiences that were studied, whether they involved inservice or preservice teachers, or both. Only eight studies investigated online PLCs experiences.
- Table 4 categorizes studied PLC experiences that entirely or substantially involved **preservice** teachers. Only eight studies strongly focused on preservice teachers in PLC experiences.

Four studies that examined both online PLC experiences and involved preservice teachers correspondingly are listed in both Tables 4 and 5. In the first column of each table, we assigned articles to the category that we have named, which may or may not be the name that authors used for the PLC in their articles.

Before discussing these tables, it is important to note that we wanted to include some other basic information but the state of it in the literature made it impossible to do so; namely: What was the level of effort of these PLCs? More specifically, how often did they meet, when did they meet (e.g., during or before/after school), for how long, and over what period of time? Some articles provided all this information, while many only gave a partial picture, and a few provided none of it. The omission of such information handicaps the usefulness of an article. A reader has to know the level of effort involved in order to accurately deliberate issues such as those below.

- What did the PLC cost in terms of participants’ time, and how difficult/easy would it be in my context to schedule such time for joint work? Could it be scheduled a different way? In my context, would there be dollar costs for any of this time?
- What does the level of effort tell me about the nature of the experience? While an article may describe the kinds of things discussed by a group, a reader’s understanding of the phenomenon is enhanced by knowing how long sessions typically ran and how many of them there were. For example, some conversations that seem sophisticated in concept to the reader, from the description of the phenomenon, could be less sophisticated in reality. Readers could infer a more accurate understanding of the PLC content or process if they have the additional information that sessions typically were only 30 minutes after school.

It is more challenging for complex content or process to transpire in such short sessions compared to the opportunities offered by an hour or more. And the processes that can occur over a progression of meetings and between them when scheduled every two weeks could be quite different from ones for monthly meetings. But many articles do not offer this precision, and instead merely state that groups met "regularly" or "often."

Table 3. Types of face-to-face, inservice PLCs studied: Range of models and their variants

PLC mode	Variation	Articles
lesson study	one cycle, one semester	Anhalt 2009, Lewis 2009, Pang 2003, Perry 2009, Pothan 2006, Puchner 2006
	two cycles, one semester	Fernandez 2006
	one cycle (multi-lesson unit), one year	Brahier 2004
	two stages over two years	Parchman 2006
	multiple cycles, year-long	Easterday 2009
	multiple cycles, two years	Borko 2008
university course plus follow-up	school-based, mixed inservice/preservice	Bahr 2009
	school-based, inservice	Briscoe 1997
	university-based, teacher leader	Dawkins 2007
collaborative action research, or collaborative inquiry groups	action research – compare approaches to increasing student engagement	Copobianco 2006
	increasing inquiry-oriented instruction	Hammerman 2009, Nelson 2007 & 2008
	improving instructional practices	Kajander 2007
grade level meetings (elementary, E) or department meetings (secondary, S)	E. many facets of instruction over 4 years	Frost 2009
	E. use protocol for inquiry into instructional problems	Ermeling 2009, Gallimore 2009
	E. culture language issues among Latina/o students re math instruction	Musanti 2009
	S. informal analysis of an inquiry-oriented lesson	Melville 2007
discussion group	monthly critical friends group	Curry 2008, Kazemi 2004
PLC insufficiently described to categorize	compare PLCs w/ and w/out university STEM faculty participation	Monsaas 2007
	administrators work with teams of teachers	Nickerson 2005

The most common kind of PLC was variations of lesson study, but there was a wide range of phenomena among this group. A full Japanese lesson study "cycle" involves joint planning of a lesson, members teaching it, group revision of the lesson through group debrief of how it went, members re-teaching the now revised lesson and a final group debrief. In Japan, it is common for teachers to go through this entire cycle about three times a year. In most articles above, one "cycle" was only a partial Japanese cycle, with the revise and re-teach stages omitted. Even so, the magnitude of the experience ranged from doing one such cycle to several, and the time span for the entire enterprise from a semester to two years. Readers may want to keep this information in mind when considering the comparability of the phenomenon to their context. Repeating our refrain, it is important to consider the level of effort in considering what to make of the study findings, and their generalizability.

If teachers in meetings at a grade level or in a department were doing some collaborative, substantive work (not administration or coordination), articles were listed as "grade level or department meetings." If lesson study was occurring in these situations, the article was instead listed under lesson study.

Joint investigations into content or instructional practices, other than through lesson study and not occurring in grade level or department meetings, were categorized as "collaborative action research" (or "collaborative inquiry groups"). If the nature of meetings was discussion about practices or content rather than joint investigation into them, the PLC was categorized as "discussion group."

If the PLC experience was occurring in the auspices of a university course that involved follow-up interactions of participants about their classroom practices (i.e., the experience went beyond only being in-class collaboration), the article was categorized as "university course plus follow-up."

In a later section describing thoughts by an expert panel in our knowledge synthesis, you will see that some panelists felt it was important to define a PLC as requiring more specifics than those in some of the articles. In some discussions, panelists even had concerns about identifying lesson study as a PLC, particularly a "thin" lesson study enterprise. Their concern is that if low-level endeavors are included in discussion of PLCs and these have limited effects, then the status/reputation of "PLC" will become that of a fad. However, for purposes of this part of the knowledge synthesis, a review of the research literature, we used a more inclusive definition as described earlier: a collaborative experience, involving 3 or more STEM teachers.

We stretched the PLC definition if the study focus was an online collaborative experience (Table 4). The informality and loose structure that can be common among online enterprises limit the experiences from being a fully conceived PLC. Therefore, we term the phenomena in these articles as PLC "experiences" rather than calling them PLCs. However, the structure and intensity of the phenomenon in articles by Barab, MaKinster and Scheckler (2003) and Friel (2000) are more robust than those in the other studies.

Table 4. Range of Studies of Online STEM PLC Experiences

Online STEM PLC Experience	Variation	Articles
discussion forum	student teachers, supervising teachers,	Friel 2000

	new teachers	
	inservice teachers	Sinclair 2006
collaborative video analysis	improving inquiry-based pedagogical practices	Barab 2003
university online-only collaborative course	preservice and inservice teachers	Silverman 2010
	inservice teachers	Balcerzak 2009
university course w/ online discussion	inservice teachers	Yang 2004
	inservice, preservice, faculty	Loving 2007
	preservice	Thomas 2008

We also stretched the PLC definition if a study was conducted with preservice teachers (Table 5). It is difficult within the time constraints in one-semester of student teaching or a weekly methods course to play out a robust professional learning community. Again, we identify the described phenomena as PLC "experiences."

Table 5. Range of Studies of Preservice STEM PLC Experiences

Preservice STEM PLC Experience	Variation	Articles
online discussion forum	student teachers, supervising teachers, new teachers	Friel 2000
university online-only collaborative course	preservice and inservice teachers	Silverman 2010
collaborative discussions	preservice student teachers, cases of teaching dilemmas	Yoon 2010
lesson study	micro-teaching in methods	Fernandez 2005
	during student teaching	Marble 2007
university course w/ online discussion	inservice, preservice, faculty	Loving 2007
	preservice only	Thomas 2008
attitude toward PLC concept (no PLC participation)	intention to participate in PLC once becoming teachers	Leite 2006

What is the Methodological Strength of Existing Research?

As a statement of fact rather than judgment, the body of research on this topic leaves much room for improvement in methodological rigor:

Overall rating, SoE	Percentage of Studies
adequate	0%
limited	15%
very limited	31%
poor	54%

Nonetheless, it is important to note that the analytical schema for the Standards of Evidence (SoE) is applicable to any research design (see Appendix D); therefore, these results were not skewed by any disadvantaging of the large proportion of qualitative studies in the set. Nor should these results be interpreted as an indictment, for several reasons. First, this new analysis method sets a high bar, so that if just one of eight key criteria among the entire set of 32 SoE is rated low, it is considered a "fatal flaw" that heavily shifts the overall rating to a low value. Furthermore, a similar distribution of low ratings has been obtained for this analysis method during recent inspections of educational research on other topics, such as STEM teacher induction, and professional development of STEM content knowledge among teachers. Therefore, readers should not infer that the quality of research on STEM PLCs is necessarily any worse than that of other educational research; rather, this reflects the rigor of the SoE approach.

On the other hand, the face value of some of the methodological limitations identified in the studies should temper readers' view of the strength of the studies' validity, reliability and/or generalizability. Among the most prevalent weaknesses were sample bias, attrition bias and/or researcher bias. Many authors did not adequately describe the sampling procedure. For example, several studies carried out in-depth investigations of only a few teachers, yet did not clearly explain how or why these particular teachers were used in the study. In other instances, the sampling procedure was described, but researchers did not take into account how sample bias might affect their results. Few studies employed random recruitment and selection of study subjects. In several studies, subjects left the study or were dropped, but researchers did not disclose the reasons, or whether these study leavers were representative of the characteristics of the entire sample.

Investigator bias was another common occurrence of a substantial limitation. In many cases, studies were conducted entirely by investigators who already may have had a prior professional relationship with some study subjects, without disclosing it or describing steps to make adjustments for the potential biases this could pose. Some studies in the synthesis were conducted by university professors studying teachers who previously were students in a course the investigator taught in teacher preparation. In contrast, some studies took the step of having more independent faculty participate in data collection and analysis in order to offset potential bias introduced when teachers are describing their practice and views of teaching to a professor who previously taught them.

Note that, in most instances, insufficient information was given to eliminate the possibility of these biases; it was less common that the provided information revealed an actual bias. However, consistent with the threshold of quality set by such contemporary appraisals as the What Works Clearinghouse, the possibility of bias must be presumed if standard information is not provided that can rule it out. One piece of good news for future research is that, whenever these biases do not exist, it typically would only require that authors write a very few additional sentences in the articles' methods description to document that fact. We do not provide the SoE ratings for individual studies in this document.

Research Findings

For each Type 1 and 2 research study, Table 6 below indicates the primary aspect(s) of PLCs that it investigated: (a) understandings about PLCs, such as design choices and experiences of participants; (b) effects on teacher beliefs, knowledge, attitudes, behaviors or intentions to change instructional practices; (c) effects on instructional practices; or (d) effects on student learning or achievement. Notice that many studies focused only on understandings about PLC design and participant experience and did not examine effects of PLCs. Few studies investigated effects on student learning or achievement. The table also identifies the few studies focused on preservice teachers in PLC-like experiences, or online PLC experiences. (The preservice experiences are labeled "PLC-like" because the short time and other conditions of preservice experiences such as methods courses or student practica inherently preclude engagement in full-scale PLC experiences.) The last column describes the kinds of findings that these sets of studies produced, i.e., what range of topics do these sets of papers discuss?

More specific findings are discussed in the following sections, which correspond to the first column of Table 6, aspects of PLCs studied.

Table 6. Aspects of PLC Studied in Research Articles

Primary Aspects of PLC Studied	**Articles** (Listed alphabetically, by first author)		**Types of Findings** (subject-specific findings emphasized)
	Type 1	**Type 2**	
Understanding about PLC experiences, design choices, etc. (not their effects)	Brisco 1997 Copiobianco 2006 Curry 2008; Ermeling 2010 Fernandez 2006** Kajander 2007 Loving 2007* Nelson 2007 Nelson 2008 Nelson 2009 Nickerson 2005 Puchner 2006 Saito 2006 Sinclair 2006 Slavit 2010	Anhalt 2009 Barab 2003* Capobianco 2006b Dawkins 2007 Friel 2000* Gallimore 2009 Hammerman 1997 Silverman 2010* Yang 2004* Yoon 2010	• provide collective authority and choices especially when addressing sensitive content issues • interdisciplinary membership limited depth on content and PCK • designing facilitation by PLC purpose, membership and context is crucial; consider active administrator support • planning interaction beyond meetings can be valuable/crucial
Effects on teaching beliefs, knowledge, attitudes, behaviors or intentions	Borko 2008 Brahier 2004 Briscoe 1997 Fernandez 2005** Kajander 2007 Kazemi 2004 Leite 2006** Lewis 2009 Puchner 2006 Sinclair 2006 Sheron 2009 van Es 2010	Anhalt 2009 Bahr 2009 Frost 2008 Gallimore 2009 Melville 2007 Melville 2010 Perry 2009 Pothan 2006** Yoon 2010	• teachers shift to more talk about content • more buy-in to teaching by "reform methods," "inquiry-oriented," etc. • increased content knowledge, even among elementary teachers with limited content background • understood more specific relationship between instruction and students' conceptions • teachers felt more

			prepared/confident to teach content
Effects on STEM teachers' mathematics and science instructional practice	Brahier 2004 Brisco 1997 Herbel-Eisen. 2009 Jansen 2009 Lewis 2009 Marble 2007** Saunders 2009 Sherin 2009 Sinclair 2006 Slavit 2010 van Es 2010	Easterday 2009 Frost 2008 Gallimore 2009 Lewis 2009b Monsaas 2009 Musanti 2009 Parchmann 2006	• increased teaching using "reform methods" ,"inquiry-oriented" approaches etc. • increased teacher focus on student math or science thinking • use more varied representations of math and science concepts • increased frequency of higher-level teacher questioning
Effects on students' mathematics and science learning and/or achievement	Pang 2003 Saunders 2009 Thomas 2008*,**	Bahr 2009 Frost 2008 Gallimore 2009	• increased student understanding of specific concepts • schools w/ PLCs increased scores

* = online PLC; ** = preservice

Understandings about PLC Experiences, Design Choices, etc.

In this first batch of studies, researchers primarily elicited "lessons learned" about the PLCs of interest. Most of these studies were not designed also to concertedly investigate the outcomes or effects of PLCs on teacher variables, instructional practices, or students' learning and achievement, which are discussed in the rest of the sections that follow.

1. Several studies, particularly earlier ones, documented the **key factors for conducting STEM PLCs and/or basic dilemmas about launching and sustaining productive PLCs** – issues about time, developing relationships and evolution toward a dominant focus on subject matter content.

Many articles mentioned critical issues about time, such as arranging a time to meet, having long enough sessions for in-depth conversations to occur, and sustaining PLCs over time for progress to occur. The main thrust of an early article by Fernandez and Robinson (2006) was a validation that preservice teachers reported liking an experimental PLC-experience (a version of microteaching) and felt it would be valuable to their teaching. Briscoe and Peters (1997) documented that participants valued the chance to share successes and failures, receive encouragement and to reflect on their teaching, all of which were seen as major departures from the typical practice of teaching in isolation.

These dimensions of PLCs are such a departure from mainstay teacher work that it can be threatening for teachers to talk about teaching issues that normally are private. Therefore, it may be critical in early stages of the PLC to focus as much or more on development of relationships, trust and socio-emotional issues as on academic content (Hammerman, 1997; Puchner and Taylor, 2006). Yoon and Kim (2010) noted that it took work to move participant conversations from being governed by a need to achieve consensus to being reflective, which can involve revealing contrasts in teaching beliefs and thinking. Anhalt (2009) pointed out that another major PLC contrast with usual teacher work is developing an analytic stance where claims are made based on evidence rather than opinion. Capobianco and Feldman (2006) found that it took explicit conversations for an action-research PLC to fully realize a purpose of "creating and warranting knowledge" that could be useful to those outside the community.

2. **PLCs having teachers from multiple subjects (even limited to mathematics and science) can limit the depth or effectiveness of work on content knowledge or pedagogical content knowledge**.

Ermeling (2010) and Gallimore, Ermling, Saunders & Golenberg (2009) reported that having job-alike teams (i.e., same grade or subject, and/or similar course) was critical to teachers sustaining and benefitting from instructional inquiry. Within a summer professional development course and follow-up in science, which had some PLC aspects in its design, Dawkins and Dickerson (2007) noted that "in programs that involve teachers from a variety of grade levels and discipline areas, it is advisable to provide an infrastructure to link teachers within the same grade/discipline."

In contrast, Nelson and Slavit (2007) found that in the first year of a multi-district PLC project, having combined mathematics/science PLCs made it challenging for the groups to focus on content. Similarly, Curry (2009) reported that in PLCs across six high schools that had interdisciplinary membership and substantial flexibility to decide the PLC focus, teachers did not choose to work on pedagogical content knowledge.

3. **Having protocols for STEM PLC work is important, but their design and use must be carefully considered and monitored.**

Ermeling (2010) and Gallimore et al. (2009) identified having protocols for inquiry into teaching as a critical aspect of PLC design. Curry (2009) further noted that specifics of the protocol instrument and its use are very important. Protocols can help ensure that conversations will be substantive and focused. However, protocols also can "reinforce ritualized patterns of discourse that can narrow depth of inquiry." Capobianco, Lincoln, Canuel-Browne & Trimarchi (2006) noted when an action research PLC focused on sensitive aspects of science instruction, members needed to be given collective authority to establish routines, negotiate an agenda and question different methodologies.

Protocols in these and other studies often included ways of using student work and thinking as a prominent component of the STEM PLC work. A study by Saito, Harun, Kuboki and Tachibana (2006) documented the difficulty of shifting student teachers from focusing on instructional practices to also focusing on the learning processes of students. A study by Slavit and Nelson (2010) particularly illustrates the usefulness of and need for more specific, detailed research and reporting on this topic; there are many ways that PLC protocols could involve student work and thinking, and understanding is needed of the affordances and limitations of them for different purposes of the PLC. The studied PLC aimed to develop rich mathematics tasks for students, ones that would more strongly engage them and increase their mathematics learning. Overall, this was accomplished. However, while the supported PLC inquiry explicitly drew upon student work, teachers gravitated toward analysis of instructional practices but did not often reveal interpretations of their students' work and thinking, or ask for similar elaborations by other teachers, or clarifications of them. The authors also note that a 30-minute meeting time for this PLC may well have made it more difficult for such conversations to occur, even when prompted.

4. **Having appropriate facilitation is key.**

Working in collaboration is so foreign to the modus operandi of teaching that facilitation is needed to make PLC work as productive as possible, as quickly as possible. Many studies made mention of the criticality of facilitation for the effectiveness of PLC work. For example, Nelson (2009) and Nelson, Slavit, Perkins and Hathorn (2008) discuss how facilitation can help participants move past problem areas such as refining inquiry questions, developing trust to share student work, making sense of student work in relation to inquiry questions, and promoting a willingness to ask critical questions about instructional decisions, classroom practices and student learning. Nickerson and Moriarty (2005) reported that appropriate facilitation was a key variable to explain differences in the effectiveness between two PLCs.

Facilitating learning with other adults is different than facilitating student learning (Hammerman, 1997); therefore facilitators of PLCs either need prior experience or training and support. Facilitators must balance competing tensions such as honoring "gripes" without letting the session turn into a "gripe session," actively working on focusing the group's conversation/direction without stifling contributions, and carrying out a facilitator role while also promoting shared leadership of the group. Nickerson and Moriarty (2005) noted that facilitators must attend to whether participants have respect for the knowledge of other mathematics teachers, and the similarity or diversity in members' depth of content knowledge and PCK. Carlson et al. describe the importance of "placing oneself in another's shoes," which corresponds to the decentering Piaget describes as critical for taking another's perspectives into account. In the Carlson study, trained teacher leaders became facilitators and were observed for their ability to "decenter" or take the thinking of other PLCs members into account. The facilitators in this study noted that consciously attending to the thinking of members of their PLCs also impacted their own interactions with students in a positive manner.

Effects on Teacher Knowledge, Beliefs/Attitudes, Foci

Many studies included an emphasis on examining how participation in STEM PLCs led to changes in a variety of teacher variables: (1) content knowledge or pedagogical content knowledge, (2) beliefs about or attitudes toward STEM teaching methods (e.g., reform- or inquiry-based approaches), or (3) teachers' foci of interest during PLC activities moving toward students' mathematics or science thinking. Studies that examined whether in fact teachers' implemented instructional practices changed are discussed in the following section.

1. **Participation in PLCs can engage teachers in discussion about content knowledge or knowledge about how to teach it (PCK), or enhance their understanding of them.**

Borko, Jacobs, Eiteljorg and Pittman (2008) noted that by the second year of a PLC, teachers became willing to engage in discussions of mathematics content and PCK in contrast to gravitating during the first year mostly toward conversations about instructional practices. Melville and Wallace (2007) and Melville (2010) similarly were struck by the fact that members of a science department were willing, during discussion of a teaching case, to strongly engage in learning about science content and specific PCK; this was a notable departure from their typical interactions during regular department meetings.

Other studies focused on resulting changes in teachers' understanding of content or PCK. Fernandez (2005) found that even elementary teachers who had limited prior content knowledge were able to learn deep mathematics concepts during a Japanese-type lesson study, as well as develop more PCK about how to teach it. Similarly, Lewis, Perry and Hurd (2009) observed increased mathematics content knowledge resulting from a Japanese-type lesson study. Frost, Verhey and Siebers (2009) reported that statistically significant increases in teachers' mathematics PCK occurred across a district where PLCs were implemented. However, other identified components of the studied professional development program also could have contributed to this result; the authors further reported improvements in instructional practice and student achievement, but these findings similarly could be confounded with effects of the larger program.

Kajander and Mason (2007) and Yoon and Kim (2010) described how teachers' knowledge shifted from procedural knowledge to conceptual understandings of content in mathematics and science, respectively. Yoon and Kim also found that preservice teachers gained a stronger realization of the level of effort required to use inquiry-based teaching methods effectively. Briscoe and Peters (1997) found that elementary teachers learned science content and PCK during a PLC. A paper by Perry, Lewis and Baker (2009) described how teachers reported increases in content knowledge that were not able to be revealed through surveys about their content knowledge. A paper by Pothen and Murata (2006) suggests teachers' PCK was enhanced.

2. **Several studies described advances in teachers' preparedness to teach content, or attitudes toward teaching methods.**

Improvements in teachers' preparedness were described as "preparedness" (Sinclair & Owston, 2006), or "efficacy" (Puchner & Taylor, 2006). A study by Gallimore et al. (2009) also addressed efficacy, reporting a fundamental shift in teachers' attribution of their students' learning toward a "cause and effect" stance, i.e., coming to believe that it resulted from their own teaching through inquiry processes.

Brachier & Schaffner (2004) reported more positive attitudes toward teaching mathematics through inquiry methods. Regarding attitudes toward participating in PLCs, Leite (2006) surveyed prospective physical science teachers after a preservice PLC experience and found that they were strongly interested in continuing to be involved in PLCs once they became classroom teachers.

3. **Findings from several studies emphasized increased teacher focus on students' mathematics or science thinking**.

Anhalt (2009) found a lesson study experience "especially enlightening" for revealing surprises about their students' mathematical thinking and the value of permitting students to make mistakes and learn from them; participants in the study by Borko et al. (2008) also were surprised by details of their students' mathematical thinking. A study of a video club found that, over time, the percentage of participants' statements that were about students' mathematical thinking increased (Sherin & van Es, 2009; van Es & Sherin, 2010). Kazemi and Franke (2004) found that having the PLC focus expressly on student work caused teachers to gain more insights about students' mathematical thinking. Bahr, Monroe, Balzotti & Eggett (2009) found that teachers more strongly believed the following statements about students learning mathematics: "Children can solve problems before being taught how to solve them"; "Children should do as much thinking as possible."

Effects on STEM Teachers' Instructional Practices

The studies discussed in this section examined whether teachers' participation in PLCs resulted in changed instructional practices. They are grouped by whether the described effects were (1) moves toward generally described practices, such as "reformed-oriented" approaches, or, more specifically, (2) increased attention to and use of student thinking or varied approaches to problem solving. Three other papers raise methodological considerations for studies of this kind.

1. **Several studies, particularly earlier ones, reported that participating teachers' practices become more "reform-oriented" or the like, described mostly in general terms**.

Brahier and Schaffer (2004) found that most teachers' mathematics instruction became more "reform-oriented," even though teachers had a wide range of prior teaching experiences and initial stances toward reform-oriented mathematics teaching. Biscoe and Peters (1997) observed teachers experimenting with new teaching methods, including "problem-based learning." Marble (2007) found that elementary preservice teachers' science lessons had improved design, pacing, assessment, student engagement, management and instruction. Sinclair and Owston (2006) observed that about half of the science classroom lessons by teachers participating in a blended live and online PLC were "stronger," and that teachers were experimenting with new teaching approaches. Although the above studies suffered methodological limitations as did most studies in the current knowledge synthesis, their findings were commendably based on triangulation of data from teacher self-reports about their STEM instructional practices and observations of their classroom teaching by study researchers, rather than relying only on teacher self-reporting.

Parchman, Grasel, Baer, Nentwig, Demuth and Ralle (2006) found that use of PLCs by a national project in Germany succeeded in having chemistry teachers design lessons consistent with "reform" instructional approaches, using a range of teaching and learning methods.

Two studies are noteworthy for investigating the effects of PLC efforts that were more extensive than PLCs in most other studies. Easterday (2009) conducted a study of the effects of lesson study in multiple school districts after this PLC model had been developed and tried over an eight-year period. Results indicate that the number of teachers' higher-order questions increased, and that they more frequently recognized and responded to students' higher-order questions. Monsaas, Mogusu and Ellett (2009) obtained survey responses in each of three years from over

2,000 STEM teachers participating in a National Science Foundation-funded Mathematics and Science Partnership project (MSP). Results were compared for teachers participating in PLCs, or not. Teachers in PLCs reported more frequent use of "standards-based teaching and learning," including science teachers in PLCs using more inquiry methods. Results were further enhanced among teachers from PLCs that involved IHE mathematics and science faculty. While effects sizes in this study were small, the results are interesting because statistically significant differences did arise over such a large population. However, the methodological rigor of these latter two studies could not be appraised because the articles were conference presentations.

2. **Six papers reported increased teacher attention to students' reasoning and understanding, or using more diverse modes of student problem-solving.**

All but one paper focused only on mathematics teacher PLCs. At the elementary level, Musanti, Celedon-Pattichis and Marshall (2009) noted that one teacher, who had predominantly bilingual students and was participating in a PLC about Cognitively Guided Instruction (CGI), moved away from didactic teaching methods. She successfully employed problem solving approaches of embedding mathematics questions within stories to which her students could relate and developed approaches to scaffold students' explanations. Gallimore et al. (2009) observed that teachers moved toward having students engage in problems before giving direct instruction on particular content whereas they previous perceived such practice as "unfair" to students. At the middle school level, Herbel-Eisenmann, Drake and Cirillo (2009) reported that PLC participants moved from personally repeating student explanations to having students "revoicing" other students' explanations. Similarly, as an effect of a video club PLC, Sherin and van Es found that teachers increased reasoning with students' knowledge instead of their own by publicly recognizing students' ideas, providing extended opportunities for student thinking and eliciting multiple methods and solutions to mathematics problems (Sherin & van Es, 2009; van Es & Sherin, 2010). Jansen and Spitzer (2009) similarly found that more preservice teachers were able to identify what students had learned and/or were able to differentiate among individual students' understandings.

At the high school level, Gallimore et al. (2009) found the chemistry teachers changed requirements for students' laboratory experiences and reports, breaking them into small activity increments with more student reflection interspersed among them. Teachers reported more well-written lab reports and better student understanding.

3. **Three papers advance methodological considerations for research into the effects of PLCs on participating teachers' instructional practices.**

Lewis (2009b) experimented with developing an observation instrument that might be used to look for such effects in mathematics instruction. Saunders and Goldenberg (2010) point out the importance in studies of PLCs, particularly ones involving many PLCs, to gauge the nature and level of PLC implementation as part of the study design. Their outside project evaluator found that implementation was strong only in 4 of 9 schools, but it was in these schools that teachers were found to increase their focus on student learning, use different kinds of assessments and more frequently perceive connections between their instruction and students' learning. Lewis, Perry and Hurd (2009) reported that one impact of the PLC was that teachers voluntarily continued it beyond the study, with all six teachers doing so the year after, and four teachers still participating six years later. Although this information only speaks to a single PLC, it is notable for two reasons: Such a sustained impact suggests that teachers found the experience to have substantial, transformative value for their teaching work; and this study is rare in giving any information about what happened after the project or the study's main data collection stopped.

Effects on Students' Mathematics Learning and/or Achievement

1. **Only a few identified studies on STEM PLCs examined effects on students' learning or achievement**.
2. **The studies investigated student differences for mathematics; none was available that focused on other STEM subjects; this is likely, in part, because there commonly are more assessment data available in mathematics.**
3. **Overall, this small set of studies gives some existence proof that teacher participation in a mathematics PLC can lead to an enhancement in what their students learn**. The case cannot yet be made from these studies that sufficient evidence exists to clearly link results on formal student assessments to teacher participation in PLCs.

A couple of studies investigated student mathematics learning that resulted from a few, short-duration teacher PLCs that had a narrow topical focus (Pang & Martin, 2003; Thomas, Qing, Knott & Zhongxiao, 2008).

In contrast, two other studies examined effects of multi-year PLCs occurring in many schools. Saunders, Goldenberg and Gallimore (2009) studied effects, in nine Title 1 schools in an urban district, of grade-level team meetings over five years of focusing on student learning in mathematics and language arts. Resulting test scores were contrasted with those from comparison schools that did not get any support to transform grade level meetings into PLCs. No advantages in scores occurred in the first two years, wherein the only support was training of principals to institute and facilitate PLCs. But in the last three years, principals and teacher leaders received onsite training for implementation of PLCs, including the use of protocols for running meetings (further described in Gallimore, Ermeling, Saunders & Goldenberg, 2009). Resulting student scores on state-mandated assessments were higher in the experimental group, including among Hispanic students. Like all research in this report, the article omitted some particulars that flagged methodological concerns in the SoE analysis.

In the second paper, Frost, Verhey and Siebers (2009) found increased mathematics achievement across a school district that for four years required PLCs focused on mathematics teaching for grades 4-8. However, results cannot be attributed specifically to the PLCs because they were one of four components in the professional development program being implemented. The article's methodological rigor could not be inspected because it was a conference presentation that lacked detailed methods information.

Bahr, Monroe, Balzotti and Eggett (2009) examined dozens of a limited-duration PLC, but one that is an unusual preservice/inservice configuration. There were about 40 PLCs running over a semester, each one led by an upper-elementary inservice teacher who was enrolled in a program for a master's degree or a mathematics endorsement. The other participants in each PLC were two or three preservice teachers from a university mathematics methods course. The mathematics scores of the classroom teacher's students were higher than baseline examination scores from the year before when no PLCs were occurring, on both a state-mandated test and a second external assessment. However, a formal SoE analysis could not be conducted because the article did not provide a sufficient amount of methodological detail.

Studies of Online PLC Experiences

For seven of the eight studies involving online efforts, the kinds of results provided primarily were limited to understandings about the PLC experiences. As noted previously, a study by Sinclair and Owston (2006) also examined changes in teachers; the authors' report from a blended (live/online) professional development program is that teachers felt more prepared to teach particular curricular areas of mathematics and science, more so in science than mathematics. No studies focused strongly on changes in teachers' instruction. Because the online environment creates the opportunity to expand the learning community beyond the local school, researchers are looking at how web-based facilitated discussion in connection with content coursework can build professional communities of content teachers across distances (Balcerzak et al., 2009). One research advantage of online PLCs is the opportunity they offer researchers for transcripts of teacher discourse both as quantitative measures of interaction and qualitative discourse resources. Also noted previously, Thomas et al. (2008) provided some limited insight into what student learning occurred from Web-assisted undergraduate mathematics courses for elementary teachers.

> **Research exists that can provide specific advice for developers of STEM online experiences to gain more and better quality participant engagement in the PLC experiences.**

There is no need today for the host of developers of online PLC experiences to begin their efforts de novo; besides learning by contrasting and comparing the features of many extant sites at this point in time, there also is research that can inform design and implementation decisions. Principals of good practice for STEM PLCs overall should be considered and applied in the design and support of online PLCs for STEM teaching.

In a seminal paper on design of online professional development, Barab et al. (2003) provided grades 5-12 mathematics and science teachers with opportunities to learn inquiry-based pedagogical practices by coming together in a virtual space to observe, discuss and reflect upon video-based teaching vignettes. The article is a detailed case study and theoretical framing of the researchers' dilemmas and experiments with design choices in the virtual space and how participants responded to them. Authors identify several "dualities" or trade-offs that need to be considered in designing a Web space for professional development; for example: (1) designed versus emergent – having enough advance structure to enable productive participation but enough flexibility to address the participants' own interests; and (2) local/global needs – teachers' interest gravitated toward immediate instructional needs like wanting lesson plans, while developers hoped to move them toward more global aspects of inquiry-oriented instruction. In a blended (live/online) professional development course for mathematics teachers, Yang and Liu (2004) found that without facilitation, teachers' online comments did not focus on the desired mathematics content.

Friel (2000) built a facilitated online discussion forum for preservice and beginning teachers of mathematics and science in the middle grades. Beginning teachers viewed the continued connection to preservice faculty as “extended student teaching” and felt they were able to make contributions for the benefit of preservice students. This early article notes a now common finding that it is difficult to get participants to contribute large numbers of written posts, as well as posts that build and sustain a thread of conversation. This finding is echoed by Sinclair and Owston (2006). Loving, Schroeder, Rui, Shimek & Herbert (2007) developed and studied a blog for mathematics and science teachers; the unstructured nature of a blog typically makes it marginal to consider participation in a blog as a PLC experience. The authors note that many more people only read posts than contribute to them, or comment on others’ posts; nonetheless, many participants who primarily read messages often still value such “lurking” in the site. Silverman and Clay (2010) fostered more sustained writings during undergraduate online mathematics courses for teachers by facilitating stages in disclosure of posts; initially a writer could only view their posts, and then all posts were released to all participants. Balcerzak et al. (2009) found that the discussions facilitated by online courses facilitated four of the five key dimensions of local PLCs described by Hall and Hord (2006): building shared values and vision, applying learning to better attend to students’ needs, creating supportive conditions and relationships, and supporting shared professional practice among peers. The element Balcerazk et al. found missing in year one of their online PLC was developing supportive and shared leadership; however, this was set as a goal for the second year of their program.

What do the Professional Education Organizations Advise? (Type 3 Knowledge Sources)

In order to ensure we have the breadth of opinion regarding STEM professional learning communities, we reached out to non-traditional information sources. To capture the growing knowledge base on STEM PLCs in practice, we expanded our search to capture current information from the field that has not yet made its way into the peer-reviewed journals. These additional sources of information include organizational advocacy statements and articles from relevant publications (Type 3 knowledge sources).

The organization advocacy pieces consist of policy and support statements, implementation models, and organization-based PLCs from education organizations. Many education organizations have begun to advocate for the use of PLCs as teacher professional development and as a best practice for improving instruction. NCTAF and WestEd developed a list of 40 major professional organizations and other education resources for STEM teaching and learning to determine how they view PLCs. We sought out well-respected nonprofit national research and advocacy organizations, and looked at those with a specific focus on STEM, as well as those with a broad education reach that includes STEM along with other fields. In reviewing mission statements or policy positions regarding professional learning communities on the organizations’ websites, we found that several organizations had created their own learning communities, many of which were online PLCs. Others had published papers or even books describing models and approaches for implementing learning communities.

The articles from educational publications include reviews, descriptions, or advocacy articles about PLCs written by researchers but not focused on a specific research project, as well as articles on professional learning communities from *Education Week* and *Phi Delta Kappan*.

Landscape of the Statements and Articles

There were 74 examples of published expert advice included in our analysis (see Table 7): 43 of these fall under the general category of policy position, or support statements; 31 are articles from non-peer-reviewed journals or newspapers. The largest percentage of the 74 examples found in our review were support statements (46%), in which an organization in some way indicated support for professional learning teams as a tool for improved teacher quality and/or improved student achievement. Far fewer (22%) of the organizations made specific policy statements or mission statements in favor of PLCs. Advocacy for content teams grouped around science was more prevalent than that for mathematics, technology, or engineering. However a number of articles did discuss both math and science together.

Although some organizations that were searched made no statements regarding PLCs (a list of organizations searched is found in Appendix E), those that did provide some discussion or statement about PLCs were all positive. The support statements characterized PLCs as a tool for improved teacher quality and/or improved student achievement. Policy or position statements generally emphasized that PLCs push educators to use skills their students will need in the workforce, e.g., scientific inquiry, problem solving, teamwork and collaboration, and critical thinking. However, little attention was paid to why PLCs are particularly relevant to STEM educators; rather, the focus was on education as a whole.

Table 7. Published Expert Advice

Article Type	% (#) of Articles*
Policy/Position Statement	22% (16)
Support Statement	46% (34)
Implementation Model	9% (7)
Org. Created PLC	9% (7)
News Article	15% (11)

PLC Content Focus	% (#) of Articles*
Math Focus	22% (16)
Science Focus	26% (19)
Technology/Engineering	15% (11)
General (not STEM focused)	58% (43)
Online Component	16% (12)

*Combined numbers exceed total of articles because some can be classified as more than one type, or address multiple content areas.

Policy, Position, and Support Statements

A large portion of the published expert knowledge comes in the form of support statements, in which the author or organization discusses the benefits of PLCs without directly endorsing them in a formal statement. Though they stopped short of endorsing PLCs outright, a great number of organizations published statements about how PLCs can encourage reflection on practice, improve pedagogy and address content knowledge (EDC, ISTE, NCTM, NEA, SEDL[1]). Other organizations point to research and case studies that discuss PLCs' positive effect teacher practice, school climate, perceptions of self-efficacy and student achievement (NCTAF, BSCS, CTQ, Ontario). Several organizations have developed information for those looking to develop their own PLCs: how-to guides, discussions of how teams should be formed to function best and principles of effective PLCs (ASCD, NCTAF, ECS, SEDL, SETDA). Others, such as BSCS, have developed instructional materials around content, but also note that the best way to support their use is to have teachers work together around the instructional material. Both of the teachers unions, AFT and NEA, encourage their members to participate in PLCs to improve their pedagogical skills.

In contrast, a smaller number of organizations made direct policy or position statements, directly endorsing teacher collaboration or projects focused on PLCs. Many organizations advocate for PLCs as a school change model, noting that PLCs positively affect teacher practice, school climate, perceptions of self-efficacy, and/or student achievement, usually based on research and/or field experiences (NCTAF, NSTA, NSDC). For example, the consensus of participants at the NCTAF 2003 Summit on PLCs was that: "(1) Teaching trumps all other factors in a students' learning; and (2) A new body of knowledge exists about how people learn. The fastest, most efficient way to ensure students reap the benefits of these findings is through learning communities."

Several other organizations have adopted PLCs and collaboration as the standard for effective education, especially in regards to professional development and induction (ISTE NETS-T and NETS-A, NCCTQ, NSTA, ISTE, NSDC). Taking it a step further, ASCD and the STEM Education Coalition both endorse PLCs and advocate to Congress for funding of PLC projects. In their 2009 Legislative Agenda, ASCD recommends policies which support "Professional development activities – such as study groups, action research and data analysis – that promote both collaborative and self-directed continuous learning and focus on student needs, results and best practice."

Finally, several organizations have created PLCs for their membership and supporters, and most of those take place in an online setting. The most common purpose for these communities is for professional development focused on differentiation, data use or content knowledge development (AFT, PBS, AAPT, ITEA, SRI). Several of these communities focus on leadership development and coaching (AFT, ASCD, CTQ, PBS).

Again, many of these organizations were advocating for the implementation of PLCs more generally, rather than specifically for STEM teaching.

Articles from Relevant Publications

A wide variety of articles in the "popular education press" have been written that address the effects of PLCs. Many of the articles highlight the "efficiency" of working together: how teachers working together can do more, faster and better than one teacher in isolation (Wagner, 2007; Schmoker, 2009; Jacobson, 2010; Johnson, 2008; Kusnick, 2008). In *Education Week*, Tony Wagner (2007) notes that "Groups are far more likely to come to a deeper understanding,

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[1] A list of organizational acronyms is found in Appendix F.

and to better solutions, than are individuals working alone, no matter how talented." Other articles in this genre are more specific in setting a theoretical framework for PLCs and listing the key elements of effective PLCs, such as trusting environments, leadership support, facilitation, support from outside experts and stable settings for collaboration (Carroll & Doerr, 2010; Carroll, 2009; Hirsh & Killion, 2009; Gallimore & Ermeling, 2010; Nelson & Slavit, 2008). Fullan (2008) and Farnsworth (2002) each discuss the importance of leadership in building and sustaining PLCs. Lieberman and Miller's (2008) article stands out in its discussion of the pitfalls of poorly implemented PLCs. There must be a balance between competing forces: voluntary vs. mandatory, community vs. pseudo community, congeniality vs. collegiality and process vs. content. The authors note, "Too much focus on subject matters may result in neglect of means to keep community functional and vital" (p. 29). Work must be practical and connected to the reality of the classroom.

Other articles point to more specific effects of PLCs. Several authors discuss the effects on student achievement in several countries that implement PLCs as a common practice: Finland, Japan & Singapore (Darling-Hammond et al., 2009; Bassett, 2008; Hirsh & Killion, 2008). Honawar (2008) and Odden (2009) see PLCs as a school improvement model. Many others describe PLCs as effective professional development, either as a theoretical framework for professional development or lessons learned from their own practice (Lumpe, 2007; Cwilka, 2004; Tinto, 1998; Wilburne et al., 2007; Schmoker, 2009; Mundry & Stiles, 2009; Stiggins & Dufour, 2009).

Finally, several articles discuss how online learning communities are different from face-to-face communities: anytime and anyplace access, focus on content and pedagogy rather than student data, and access to a more diverse and widespread community (Sawchuck, 2008; Riel & Fulton, 2001; Falk & Drayton, 2009; McAnear, 2007; Barab, Kling & Gray, 2004).

Guidance from an Expert Panel of Researchers and Practitioners (Type 4 Knowledge Source)

Adding greater depth to this synthesis are the voices of practitioners and researchers from our expert panel. A group of seven practitioners and researchers currently working with PLCs were convened for four rounds of online activities, to provide input and feedback on the information that was compiled from our analysis of the peer-reviewed research as well as the published expert advice. The panel had varying types of experiences working with PLCs; some worked with preservice teachers, others with novice teachers, experienced teachers or combinations of the above. (See Figure 1). All seven panelists have guided PLC groups; three have researched PLCs and five have themselves been participants in a PLC. When asked why they were involved in PLCs, six cited a personal belief in the efficacy of PLCs, three cited an outside requirement to do the work and six cited a personal interest in the topic.

Expert

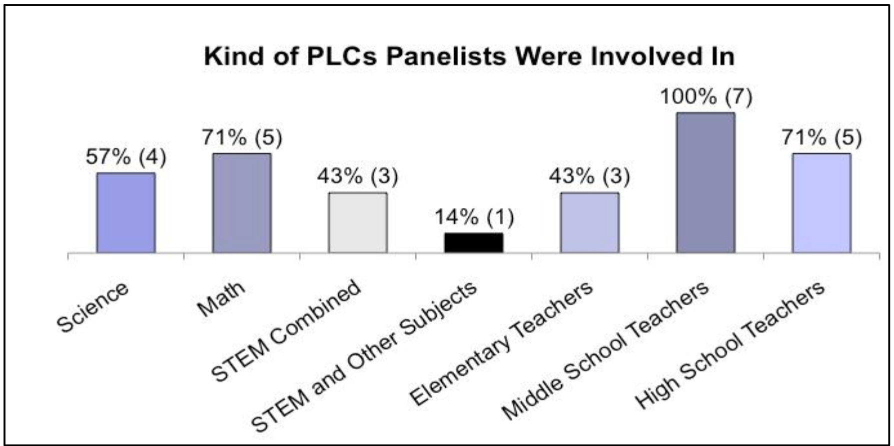

Figure 1. Panel PLC Experience

Participants were engaged in three rounds of questions posed in online surveys, with each round followed by an online discussion session. The first round of survey questions focused on the panelists' backgrounds and basics beliefs about how PLCs function and effect teaching and learning. The online discussion that followed further developed our understanding of the panelists' beliefs and pushed the panel to outline the key characteristics of effective PLCs. The second survey asked the panelists to reflect on general ideas about PLCs that were based on our research synthesis, and the following online discussion formed around their survey responses. The third and final survey asked the panelists to react to specific statements about the most effective ways to develop and sustain PLCs, and again the online discussion dug deeper into the panelists' reactions to those statements.

A list of online panel participants, a list of the survey questions and a discussion outline from online webinars are available in the technical guide. The content of the discussions is summarized below.

What is the Appropriate Definition of a PLC?

Some online panelists were concerned about our definition of a PLC. We recalled that, in searching for research and knowledge sources about PLCs we used an expansive definition: PLCs involve three or more participants, they include mathematics and/or science teachers, they involve either just teachers or teachers plus other participants, the PLC participants are engaged in joint learning or work, and the PLCs address a wide range of aspects of teaching. The panelists encouraged us to include student learning in the definition because PLCs should focus on student work and learning.

One panelists discussed DuFour's distinction between "collaboration vs. co-blabaration," meaning that, when a PLC is not focused on student learning, it's just a lot of talking and sharing. The group may not be using data that confirm that what they are doing is working, so they continue to do it anyway. There was also discussion of the "continuum of collaboration," beginning with breaking the isolation and moving toward deeper conversations during which teachers develop "habits of mind" and reflect on the impact of instruction on student learning. PLCs were described a "dynamic"; there is a continuous evolution. One panelist noted that when teachers rated themselves on the PLC continuum, the more involved the teachers were, the more accurately they rated themselves. She noted that teachers who had engaged in authentic PLCs were more realistic while, ironically, those who were not trained thought they were doing better!

Many of the research articles that came up during our search were about lesson study groups, based on the Japanese model of lesson study. The online panel responded to a question about whether or not they believe that lesson study constitutes a PLC. The consensus was that, while lesson study can be part of a PLC, it is not automatically a PLC in its own right. They commented on the fact that lesson study groups are typically focused on a particular lesson or series of lessons, while PLCs can have a much larger goal or focus. Additionally, lesson study does not focus on shared goals or vision, which all maintained is key to an effective PLC.

When asked about PLCs in preservice education, the panelists generally agreed that engaging student teachers in PLCs in the school where they are assigned can be a very positive experience. One panelist reported that she worked with student teachers who experienced PLCs in the schools where they were assigned for student teaching, but then hired in schools that did not have PLCs – they all requested to return to the PLC schools. One panelist suggested that “working in PLCs” as a consideration for placement of student teachers in schools might be a good policy. “They would develop the skills to know when they are in a PLC with the high level of conversation that involves, versus “meeting talk.”

What are the Differences Between STEM PLCs and PLCs in Other Content Areas?

We probed the online panel about what they saw as the differences between a STEM-focused PLC and a general PLC. In the case of STEM PLCs, the dialogue of the team members clearly focuses particularly on student learning in STEM areas. The panelists felt that the focus is more likely to be on the development of content knowledge than is the case in a general PLC. STEM teams are more likely to identify instructional strategies to engage students in STEM issues and to discuss how what the students are learning relates to their lives and future careers.

Several panelists felt that math and science lend themselves to PLC work more than social studies or language arts, due to the scaffolding of skills found in math and science. (Another panelist suggested, however, that most disciplines scaffold learning from one stage and grade level to the next). While one panelist working in high schools and middle schools had found it easier to implement PLCs in science than in math, finding it harder to build a dialogue around math, others disagreed, suggesting that math has more of an obvious sequencing for collaboration, which can become a framework for discussion. Furthermore, there is an increased pressure for improvement in math teaching due to NCLB testing requirements. However, others felt that science teachers have common tools (i.e., inquiry methods) that can be a vehicle for collaboration. Science teachers are also used to working together in labs and on lab schedules, so the transition to collaborating on student data and professional learning might be easier.

Most panelists agreed that for PLCs to work across content areas would likely be more difficult than PLCs working within one content area. Those panelists with experience working across subjects felt that finding points where the curricula cross was a challenge and can feel forced (unless they were working on an interdisciplinary course). However, one panelist suggested that a good facilitator can help teachers see the connections across content areas in such skills as accessing and synthesizing information from charts, graphs, diagrams, maps, etc. The panelists suggested that making connections between math and science is often a primary motivator for STEM PLCs. As one said, “In order to better integrate content and inquiry between disciples of science (physics, chemistry, biology, Earth science), PLCs are necessary. Taken to another level, to infuse math or engineering (design and process skills), PLCs are even more important in order to blend content and process.”

What are Key Factors for Effective PLCs?

The panelists laid out what they thought were some of the most important factors for implementing and maintaining an effective PLC. Their views closely paralleled recommendations found in our Type 1, 2 and 3 knowledge sources and the general models described in the Type 5 knowledge souce discussion below. Despite their having worked in and with varying levels and types of PLCs, their agreement around key factors for PLCs to be effective was notable. Among these factors are:

1. The first factor, which they cited as the most important, is to establish a common vision, mission and goal for the PLC. All team members must understand and buy-in not only to the importance of their PLC, but also what the goals for their PLC are.
2. It is imperative that teachers draw the connection between their teaching and student achievement. Stakeholders must also have an understanding of what work is really involved to get to improved student achievement.
3. Members of the community must be trained on the processes and feedback loops of PLC work. The community must also work together to establish group norms, expectations and processes so that they are accountable to each other and the school leadership.
4. One panelist suggested that there be special attention paid to the protocols for engaging in student data analysis and assessment.
5. Another suggested that in her research of high school PLCs, with varying formats and activities, the key to success was the principal. "The key to pushing the conversation to student learning and instruction was the relationship to the principal. In PLCs where the principal attends sessions regularly there was more substance to the discussion. Those without a clear leader lacked structure." Others confirmed that a good leader is critical at all levels of schooling, not just high school.
6. Continuity matters as well. As one panelist noted, "In a PLC with lots of turnover (e.g., with many Teach for America teachers) the PLC work could not advance because the culture kept changing and they didn't develop a common language."

Is there a Minimum Threshold of Activity for PLCs to be Effective?

We asked the panelists if there was a minimal threshold of collaborative activity (e.g., size of group, frequency of meetings and amount of time spent together) to make a PLC worth the effort. Conversely, is there a point when it is detrimental to engage in PLC work if it is not done "right"? The panelists had no set guidance for our "minimal threshold" question. One panelist suggested that working with large groups, while not as effective as small groups, is possible but requires a very skilled facilitator and often means breaking a group into smaller groups – referred to as "professional learning teams" with the whole school as the "learning community." Most felt that smaller groups lead to more dynamic conversation, with all teachers' voices heard.

In general, however, although we probed this question in several ways, the panelists usually reverted back to discussing what they thought were the key factors for success. One panelist gave four factors that must be in place for minimal effectiveness: 1) commitment to connecting professional learning and student learning, 2) agreement on why the group meets, 3) structures in place to ensure continuity, and 4) archiving/documentation of teacher learning and the impact on student learning. Another suggested that their minimum requirements for success were developing inquiry questions, establishing group norms, setting SMART (Specific, Measurable, Attainable, Rigorous and Time Bound) goals, using common formative assessments, using common corrective instructional strategies, applying data analysis, and maintaining a shared vision and goals (these too reflect the elements found throughout the research reviews).

Several panelists pointed out that there is a continuum of collaboration which moves from discussion of activities and instructional practice to a deeper analysis of the relationship between instructional strategies used and student learning and data. While the focus might be on content early in their collaboration, it will deepen to student learning as the PLC participants grow comfortable with each other. However, they felt that PLCs are most effective when they move to discussing evidence of student learning (student class work, benchmark data and achievement data) as soon as possible. One panelist suggested that bringing in student work from another class (i.e., not that of the teachers in the PLC) can be used to open the discussion with less sense of threat to the teachers and can accelerate the process of building trust. One panelist described using pre-tests as the student work under discussion. "The teacher had not yet influenced the learning being tested, so it was 'safer' to share this with colleagues in the PLC." All panelists agreed that any ongoing collaboration is better than traditional one-shot professional development workshops.

If there is a Good PLC in a School, does this Negate the Need for Other Professional Development?

The consensus was that professional development should support what comes from the work of the PLC, not exist as a separate structure. In an ideal setting, professional development will be designed for teachers as a result of needs they encounter as they meet in PLCs. For example, teachers may find they need training in the analysis of student data or in how best to use student work samples in a PLC. They may need additional training in the development of formative assessment techniques that provide them with information about how well students are mastering the expectations in the standards and curriculum they are teaching. One area of need seen in many PLCs is helping teachers adjust instruction to meet the needs of diverse learners and determine next steps when they discover that not all students have acquired the knowledge and skills from a particular lesson. When teachers have learned new ideas or refined their skills during a professional development session, they can then discuss the implementation of the knowledge and skills as they meet in their PLC, thus providing immediate follow-up from a learning experience and increasing the odds that the new learning will be used effectively.

What is the Role of the Facilitator?

It was suggested that PLCs are enhanced when the role of a facilitator is included in the design of the PLC. The panel discussed whether the facilitator could be a member of the team or if they had to be an outsider. While a peer facilitator may have some trust established within the group, it can become uncomfortable if it is necessary to deal with a group member who is not fully participating. Then the facilitator is put in the difficult situation of being both a peer and a superior. Some panelists felt it was important for the facilitator to be able to remain neutral and not have to participate in the PLC.

The key role of the facilitator is to ensure that the group stays on track, working toward their shared goal. One panelist felt that the facilitator should ensure that everyone is in the same boat because "people don't shoot holes into boats they are in." The facilitator should push the conversation when necessary to ensure the process continues and should keep the discourse focused on student achievement and teacher learning. Facilitators set the tone for the group. They communicate clear expectations, build capacity for participation, and monitor and reflect on practice.

Panelists also felt that a facilitator with content expertise was more beneficial than one without content knowledge in the field. A content knowledgeable facilitator can push the conversation and add his or her own content expertise. Although a "generic" facilitator can discuss pedagogy or data analysis in general, this jeopardizes the group moving to greater depth content wise. However it is important that the facilitator not be seen as the only expert, as the teachers are all contributors whose expertise must be acknowledged and valued.

The panelists agreed that, regardless of their content knowledge, facilitators require training in facilitation, coaching and data analysis. The training should be followed-up over time rather than being a one-time occurrence. It is important for a facilitator to have an understanding of the realities that teachers face (e.g., standards, pacing guides, etc.) so that the group can take those into account when discussing their goals and plans.

Should PLCs be Voluntary or Mandatory?

The panelists felt there would be much less tension in a voluntary PLC; however it would be easier to put the support structures in place when the district initiates the idea of setting up the PLC. One described voluntary PLCs as nothing more than "collaboration without a formula." A district-wide initiative requires consensus from the top level about what implementation looks like, and that needs to be communicated to the school administrators and teachers. Whether the PLC is voluntary or mandatory, every stakeholder must be prepared for PLC work; otherwise the time spent in PLC meetings turns into conversation time without direction, making it feel like a burden rather than an effective process. The district must work toward supporting the buy-in of all stakeholders; especially in circumstances where PLC participation is mandatory. This includes everyone from Boards of Education down to the parents. As one panelist said, "When PLCs are mandated, there needs to be a foundation set as well as an understanding by the staff that fits the culture of a school district, or chances for success are less likely. Parents need to be informed and also agree with the district philosophy that if instructional time is taken from the school day it is in the benefit of their children." This panelist maintained that, without this buy-in, parents will want the PLCs to meet after school rather than on school time.

How does School Leadership Impact PLCs?

Panelists described a school administrator's main role in PLCs as setting the tone in the school and in PLC groups. The principal's role is to set expectations that being a member of a PLC is an essential part of the work of teachers and to establish a culture of collaboration within the school. Leadership at all levels needs an understanding of how PLCs work so that they can determine how they can best support PLC work. They set the context and structure for collaboration: time and space to collaborate, support for PLCs in the form of ongoing professional development when needed, and the ongoing monitoring and data gathering to determine the effectiveness of PLCs.

Panelists agreed that some level of participation of the principals in the teams is needed to provide further support (e.g., outside help, more time, motivation, etc.). However, panelists felt it is inappropriate for the principal to serve as facilitator; there is a balance that each principal must find between participating and allowing their teachers some autonomy. The principals must support teachers in allowing them to direct their own professional learning. One panelist stated that the principals must work as the "lead teacher" since teachers are adult learners that need support to reach their full PLC potential.

Principals must also do some level of monitoring to ensure that real PLC work is happening. They may participate on occasion, monitor agendas and meeting notes, or have presentations from some of the team members. Some researchers have developed matrices to measure both the level of implementation and the effectiveness of PLCs; these can be useful tools for principals to use with their teams. As one panelist said, "As an administrator, I don't know how you could claim to have a successful PLC school if the administrator isn't highly involved. PLCs give teachers the power to direct their own learning and development, but there is a difference between power and autonomy…. Teachers will say they don't want complete autonomy – they want administrators' support and resources…. We can't be effective in support if we don't know what is going on."

What is the Role of the Internet in PLCs?

Several panelists have done extensive work in online communities; their thoughts are highlighted here. They noted that online communities are different than face-to-face communities because they are not space and time limited. Communities can access each other anytime and anyplace. However they must also take the initiative to engage. Participants can also self-select to participate in online communities that address their specific needs/areas of expertise. Online communities often feature more discussion of pedagogical content knowledge (application of content) as opposed to student work or data, because in many online PLCs there are no common students or classroom settings. Their discussions are then about adapting content to a teachers' context. Finally, an online facilitator is more likely to be serving as an expert than as a peer facilitator. The online facilitator should have a lot of answers, or know where to go for the right answers. He or she may be the most active participant in the community and needs enough knowledge to keep the conversations both flowing and helpful.

In addition to strictly online communities, the panel felt that technology is now seen as a great support for face-to-face communities as well. An online platform can make it possible for the conversation to continue after and between meetings. It can also function as a central repository for information and other collaborative materials.

Discussion of Models (Type 5 Knowledge Source)

Overall, what we found under this knowledge source were generally descriptions of individual projects, ranging from small teams within one school (e.g., Giglio, Viadaro, Hoban & Hastings; Kotelawala; Ellinger) to a few cross-district projects (Bornemann et al.; Kolenda), cross-project descriptions (Kennedy, Slavit & Nelson; Lieberman & Miller), or reviews of large projects (Sinohara & Daehler). We break our discussion in this section into some of the key elements of models found in mathematics and science PLCs, as well those found specifically in preservice, online, and STEM PLC reports from other countries.

Key Elements of Models in Mathematics and Science PLCs

Overall, the key features, elements and implementation issues for the identified STEM PLCs were not different from those identified in "generic" PLC research noted above – supportive, shared leadership; collaborative learning with student needs focus; shared vision and values focused on student learning; supportive structural and interpersonal conditions; and shared practice (Hord, 1997; 2008).

However, our review found that STEM PLCs may have very specific components that support these generic PLC components. This cuts across both mathematics and science PLCs. For example, in the closing chapter summary for a book comprised of several authors' reviews of key aspects of PLCs (mostly in mathematics or science), Kennedy, Slavit and Nelson (2009) maintain that the following are "essential supports" for "supporting collaborative teacher inquiry" (SCTI):

1. **Facilitation**. This is broken into 3 types: (1) knowledge facilitators, who suggest or direct participants to strategies or knowledge; (2) process facilitators, who attend to the interactions and structure of the group for equitable and productive work; and (3) focus facilitators, who keep the group on target.
2. An **inquiry stance**, one that nurtures "internalized disposition...conducive to pondering, questioning, seeking to satisfy curiosity" (p. 170).
3. Building teacher commitment by **engaging teacher choice**. This was defined not so much as choice regarding voluntary versus mandatory participation, but choice in what the focus of the inquiry will be. They suggest that activities grounded in teachers' questions and concerns are important to build motivation for and investment in the work.
4. **Support for teachers' effective use of data**. But data was used more to "improve" teaching than to "prove" that their teaching was successful. Thus, it uses student work as its most common data source, and test scores and achievement as a means for teachers to build their "data literacy" more broadly.
5. **Aligning resources to bring coherence** to the activity, in light of competing agendas of reform, philosophies and other professional development activities.

Other models of PLCs in math also focus on the opportunity to create and support a professional level of discourse among teachers. Reports on PLCs in math at the elementary level describe how having the opportunity to discuss mathematical concepts in depth with peers and supportive facilitators benefit teachers who previously may not have had either the opportunity or the desire to study mathematical concepts beyond the basics. For example, recognizing that many elementary teachers have anxiety of or even a "distaste" for teaching mathematics, Ellinger describes a "lesson study light" model he and another researcher developed with elementary school teachers at a school in California (Ellinger, 2008). In what became known as the Math Lesson Study Project, the two researchers, originally perceived as "outside experts," began by teaching lessons in the elementary teachers' classrooms, inviting the other teachers to critique both the strengths and weaknesses in those lessons. Having the opportunity to bring their knowledge of the children's developmental levels and understandings gave the classroom teachers an empowering sense of expertise, emboldening them to critique mathematics "experts." This gradually led to the development of comfort with respectful direct feedback with one another.

Elements of the Math Lesson Study Project model involved:

- weekly grade-level collaborative meetings,

- group planning,
- debriefings from frequent peer observations, and
- reviewing the work of students and the development of discussions around fundamental mathematical concepts.

Teams of teachers worked in triads to plan a lesson, while others observed the lesson, then gathered examples of student work and discussed what did or did not work in meeting the desired student understandings. Teachers videotaped each other to assist in the analysis and sharing, and engaged in online journaling (blogging) with questions, comments, compliments and concerns. The online format became a place to post materials and share plans between meetings, and to share reflections.

In models such as this, researchers report changes in the individual teachers as well as in the school environment. In the case cited above, it was reported that the trusting relationships "permeated the entire grade level and, in time, the entire faculty." They reported that "teachers took their sequence of instruction more seriously and...were no longer hesitant to request meetings with teachers of higher and lower grade levels so that they could reach agreement on mathematical language, support English language learners and review issues of assessment" (Ellinger, p. 83). These teachers' interactions across grade levels are particularly important in math, where the development of deep understandings of fundamental concepts at each stage of learning underlines the growth of mathematical skills and understanding.

The introduction of what were called "rich mathematical tasks" in the three year Partnership for Reform in Secondary Science and Mathematics (PRiSSM) project in southwest Washington led to similar changes at the high school level (Bornemann et al., 2009). This model created PLCs with three core activities:

1. two week inquiry cycles focused on the use of rich mathematical tasks,
2. two additional ninety-minute meetings focused on analyzing student work, and
3. peer observations.

Participation was mandatory, a feature that was credited with engendering both positive (i.e., all were staff involved) and negative (e.g., issues of teacher buy-in) outcomes. Adjustments were made along the way (e.g., originally the inquiry cycles were one week but were later extended to two weeks to allow for more exploration of teaching and learning strategies); also, the thirty-minute time frame for before-school meetings did not always allow time for deep discussions. Nonetheless, the participants reported that the culture of the entire mathematics department changed, crediting this to the engagement of all participants in highly structured conversations with a common focus around student mathematical thinking and how teachers' instructional approaches impact that thinking.

Furthermore, what does seem to be explicitly valued in the STEM PLCs is the **opportunity for teachers to build shared language that supports pedagogical content knowledge**, "in an environment of collaborative, professional inquiry – one that is rich in talk about scientific meanings in conjunction with a focus on student thinking and critical analysis of practice" (Shinoharma & Daehler, 2008, p. 2). For example, in model descriptions of **science-focused**

PLCs researchers found the PLC experience can provide teachers the opportunity to explore fundamental questions regarding the nature of science. These are not the kinds of discussions typically held in faculty lounges, or even faculty meetings. For example, in the APEXST (Advancing High Leverage Practices by Examining Student Thinking) project (Thompson et al., 2009), groups of 8-12 teachers met in "critical friends groups" over the course of a year, some for two hours each month, some for three full days over the course of a year. What was common was the "principled and collaborative analysis of practice" and a form of "inquiry [that was] itself scientific" (p. 52). Examining student work as a team in this model was designed around a five-step process:

1. collaboratively defining a vision of worthwhile learning,
2. teaching lessons and collecting samples of students' written work,
3. analyzing that student work and uncovering trends and patters of student thinking,
4. linking these trends with new opportunities to learn, and
5. enacting change and reporting back to peers.

Of note in this model is what the authors called the importance of several forms of accountability – *accountability to peers* by bringing in student work that teachers are ready to discuss, and engaging in the discussion with peers; *accountability to science* by exploring a scientific explanation of the phenomenon present in the work samples; and *accountability to the student work* itself as a basis for understanding where changes in instruction could positively impact student understanding.

The "accountability to science" supports what Palincsar et al. (1998) refer to as the importance of a community of practice to move teachers closer to the "scientific workbench" model of advancing knowledge about practice in the scientific community. This focus on advancing the learning of the community (in this case, the science community) is in contrast to the current professional development/teacher learning model that does not get beyond the learning of the individual teacher.

One of largest studies of PLCs in science was that of the project Understanding Science – a model engaging 1,000 teachers, 20 states and impacting 18,000 students – used at preservice and inservice levels (Shinoharam & Daehler, 2008). In this model, the elements were:

1. examples of student thinking (not their own students' work) as the unit of study,
2. guided facilitative interaction, and
3. opportunity for teachers to discuss content in the context of pedagogy – as a framework for PCK – with others in trusted environment.

What they found as critical elements were the creation of group norms (again, for the building of trust and professionalism) and scaffolding of learning as teachers took on increasingly more roles and refined their ideas and skills. This study highlights issues that may be unique to science PLCs; namely, that the collaborative environment is important as space for teachers to raise fundamental questions about the nature of science and science learning as an "interpretative process," that the same evidence or idea can be construed in many different yet correct ways, and that more people and more observations lead to more accuracy.

Preservice models

We were interested to see if descriptions of models engaging preservice teachers were similar to those focused on inservice learning for teachers already in the classroom. Unfortunately, as described earlier, we found only a small number of articles dealing with preservice STEM PLCs. One described a program begun in 2000 to recruit, prepare and retain prospective math teachers through forming a "close-knit learning community" throughout the four years of the teacher preparation program. In this design, candidates were "immersed" in "overlapping communities (e.g., university teacher education community, internship classroom/mentor community, classroom community and school community) throughout their undergraduate studies" (Artz & Curcio, 2008). While these communities did not engage in all the elements found in other PLCs (i.e., shared analysis of student work, reflection on each other's teaching), the participants rated the opportunity to meet and work together in small groups as the aspect of the program they found most valuable. Of the 81 original participants in 2000, 75 graduated. Sixty-eight began teaching mathematics immediately after graduation; only 3 left the field between 2002 and the time the article was published in March 2008.

Online models

The typical model for STEM PLCs is a group of teachers working in the same school, either in grade level (in elementary schools) or curricular groups (as in high schools). Some PLCs are also reported across districts, with teams meeting face-to-face in afterschool, summer or weekend workshops. Morris et al. describe in "The Power of Two" a model that links external workshops with in-depth follow-up work in school-based study groups or teams (Morris et al., 2003). However, increasingly when PLCs extend across a district, a state or internationally, it is the availability of online tools and facilitation that makes possible the interaction of STEM professionals working together in a virtual PLC**.** One model discussed an online community of researchers, graduate students, high schools teachers and students from six schools in Quebec and Mexico, collaborating around integrating science topics for students that spanned curricular disciplines (Vazquez-Abad et al., 2004). While not a "pure" PLC, the study described the role of collaborative tools to support the social construction of knowledge, and the importance of management tools and technical support, also providing a cautionary view of how cultures (calendars, values, and approaches to group work) can also impact PLCs across distances.

Other research reports on online PLC models like PBS Mathline (Weidner, 2002) provide guidance on this emerging trend. These models have similar components (i.e., student work can be shared through online files, teachers can be observed through videotaped lessons, reflection and discussion and collaborative design can all take place online); however, the areas that seem to be of particular concern in these models are the importance of trained facilitators and new designs for engaging participants when face-to-face interactivity is not possible. The skill of the facilitators (Newell, 2002); availability of collaborative online tools (e.g., interactive whiteboards, video/audio, text chat space, shared workspaces); and the stability and friendliness of the platforms are key components for effective online PLCs (Heath et al., 2005; Riel & Fulton, 2001).

International models

Our review of models also included those conducted in other countries. These showed little variance among or across models described in schools outside the U.S. For example, Hoban and Hastings (1997) described an intense, three-year professional development program for what they called an "action learning community" of three science teachers in a small high school in Australia. The key components identified in this community were:

1. reflection (teachers analyzing practice),
2. community (sharing ideas with colleagues in regular meetings),
3. action (trying out ideas generated from group discussions), and
4. feedback (in this case, the feedback came in the form of interviews with the students describing their learning experiences).

There are also numerous examples of lesson study and learning communities being conducted around the world. Citing as examples projects reported in the United Kingdom, the Netherlands, Japan and Australia (Bolam et al., 2005; Visscher & Witziers, 2004; Stigler & Hiebert, 1999; Kemmis & McTaggart, 1990), Emerling (2009) says the programs and challenges they face are not unique to the United States. Stoll's review of the literature of PLCs internationally did not discuss models, per se, but found many common definitions, elements, stages, impacts, processes, influences, support and hindrances – calling the promise of PLCs for capacity building for sustainable improvement a "hot topic" in many countries (Stoll et al., 2006).

Implications for Research

The landscape of research articles (discussed in the *What does the Research Say?* section) suggests gaps in the body of research that might be addressed in the future by pursuing more studies that are:

- focused on **science teachers** in PLCs;
- focused on PLC aspects possible in **pre-service**;
- focused on actual **changes in teaching** rather than changed beliefs, or intentions to change;
- focused on immediate and long-term **student learning outcomes**;
- focused on or including the role of an **online component**;
- **quantitative** in nature;
- **comparing models of PLCs** rather than a single PLC model;
- investigations of **PLCs happening in the field**.

The last point addresses the fact that no extant studies directly focused on providing the status and nature of PLCs happening in the field at large. Understandably, researchers can more readily pursue understanding of particular PLC projects that they either have a role in, or with which they are already familiar some other way. But given the fact that organizations in STEM education and leading professional development organizations universally support or recommend the use of PLCs at this point (as described in section IV-B), there likely is a great deal of PLC activity happening across the country. We are not aware of studies that yield a snapshot of the level and nature of this activity. The last national survey of mathematics and science teachers by Iris Weiss and colleagues (Weiss and colleagues, 2002) was a decade ago and did not delve into this phenomenon in specific detail.

Even among studies seeking understanding of particular PLC projects, few were conducted in locales other than those where the PLC was developed and being tried, and few by researchers who were independent of the projects under study.

Implications for Practice

Professional Learning Communities are a growing phenomenon that could deeply impact STEM teaching in K12 classrooms, and are enthusiastically advocated for and supported by both practitioners and the researchers studying them. In our knowledge synthesis we found a number of emerging principles that STEM practitioners and researchers consistently identify as important for success. These principles or dimensions are similar to those identified for PLCs more generally. There is also consistency and synergy between what was found in this study and other NCTAF work around the importance of breaking down the isolation of teaching and making it possible for teachers to learn from their colleagues as part of learning teams.

Although throughout this study we found that the elements, dimensions, or principles important for practice were highlighted using a variety of terms, overall they remain relatively consistent in their refrains. Below is a synthesis of these key dimensions identified throughout this knowledge synthesis:

1. **Common vision and shared values**: Our expert panel ranked this as the most important factor and its importance is affirmed by most researchers. This shared vision emerges from a collaboratively defined understanding of what constitutes worthwhile student learning, with all members of the PLC working together on problems around that common vision.
2. **Collective responsibility**: This element requires participants to contribute and share their expertise, and also share a sense of accountability for the student learning that is being supported. One of our panelists described this as making a connection between one's own professional learning and student learning. It involves setting group norms, expectations and processes to which members hold themselves and each other accountable.
3. **Leadership support**: School teams need the support of principals and other school leaders, who give the members space and dedicated time to meet. Leadership support also means empowering the members of the group to make decisions based on student needs. The leadership allows for a climate of trust, but provides appropriate catalysts to assure that teams are meeting and working together. Continuity over time is also important, since it takes time for the trust to be built and more time to build a common language, norms, and protocols that work for the particular PLC.

4. **Good facilitation**: Kennedy et. al. (2009) talked about three types of facilitator roles: knowledge facilitation to direct participants to information or strategies; process facilitation to attend to the structure and interaction of the groups; and focus facilitation to keep the group on target. Facilitation--whether face-to-face, online, or a combination of the two--requires engagement, tact, careful "listening" to what is said and what is not said, as well as content and pedagogical knowledge.
5. **Use of data and student work**: Because the work of the PLC is focused on student learning, members of the PLC need to become comfortable working with a variety of authentic measures for gauging changes in student learning and teaching effectiveness. Observing each other teaching and providing feedback loops and protocols for reflecting on practice are also often used as key elements in the work of the PLC.

Implications for Policy

There are several policy implications to be drawn from this knowledge synthesis. If PLCs continue to expand, it is important that structures are put in place for supporting them appropriately. These policy supports flow from the principles listed above.

1. **School staffing designs can build on the collaborative learning that occurs within a PLC.** If teacher collaboration is seen as the norm, rather than the exception, the structure of the school day and the deployment of school staff will be very different. **Creating common planning time** for members of the PLC is one basic school design change that supports teacher collaboration. Another support at the school level is to **devote professional development time and funding support to PLC work**, and use the outcomes of the PLC as the basis for decisions regarding further staff development needs. **Incentives that recognize the contributions of members of PLCs** are also important signals that the work of PLCs is valued professional activity. It is also possible to **create new roles for teachers who wish to become trained PLC facilitators**; this can engage teachers part time who might otherwise leave the classroom due to childcare responsibilities, retirement, or other issues.
2. If they are to become knowledgeable supporters of PLCs for STEM teaching, principals and other school leaders need experience with PLCs. Some are creating their own principal groups as a way of "walking the walk" and becoming familiar with the dynamics, opportunities, and challenges of PLCs. **Principal preparation programs, like teacher preparation programs, should highlight this form of school organization and professional work** and build understanding of how it can be a support for school improvement goals.
3. Even in a face-to-face school setting, there are **opportunities to expand the work of the PLC using online resources.** These options are worth exploring, especially as powerful mobile technologies expand anywhere/anytime opportunities for professional collaboration.

4. Finally, as noted in the research discussions above, we have not taken the pulse of the "naturally occurring PLCs" and their impacts. Given the nature of research grants, the published knowledge to date (research, advice and models) overwhelmingly focuses on specific projects that were doing PLCs or created ones for purposes of the research study. Few have sought out STEM PLCs for study wherever they are found. Many school districts likely are collecting **evidence of the effects of PLCs (evaluations, if not research) and these, along with independent case studies as well as collection and analysis of such local existing evidence (for example, teacher research and published blogs) could be valuable sources of knowledge.**

Collecting and analyzing local data (qualitative and quantitative) could go a long way to support the long-term implementation of PLCs. Without such data, PLCs to support STEM teaching and learning could become another educational fad, another "reform du jour" that cynical educators have seen come and go. This would be unfortunate, given the overall positive results we have found and the widespread enthusiasm of PLC participants. Like any educational innovation, it will live or die based on data-driven decisions made by those in a position to drive educational practice—policymakers at all levels. While teachers may say: "I would never go back" (to teaching without the support of a collaborative PLC), without a strong research base to prove the efficacy of PLCs in STEM teaching, educators may find school and district policies could once again shut the door on collaboration and reinforce the isolated teaching model of the past.

Appendix A – References

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Type 4

Expert Panel—see Appendix C: List of Expert Panelists

Type 5

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Appendix B – List of Advisory Board Members

Shirley Hord is a Scholar Laureate with the National Staff Development Council, and formerly Scholar Emerta with SEDL's School Improvement Program. She has written extensively on Professional Learning Communities.
http://www.sedl.org/pubs/catalog/featured_authors/shirley_hord.html

Tamara Holmlund Nelson is Assistant Professor of Science Education in the Department of Teaching and Learning at Washington State University, Vancouver. Her current research focuses on secondary science and mathematics teacher development and systemic change through collaborative inquiry in professional learning communities.
http://education.wsu.edu/directory/faculty/nelsont

Margaret Riel is a senior researcher at the Center for Technology in Learning at SRI International and Professor at Pepperdine University's Online Education Doctoral program. Her research focuses on the relationship between teacher learning and instructional practices mediated by technology, with special interest in social network analysis.
http://ctl.sri.com/people/displayPerson.jsp?Nick=mriel

Jim Stigler is a professor of Developmental Psychology at UCLA, Director of The TIMSS video studies, and founder of LessonLab, and co-author of *The Teaching Gap* (1999) and *The Learning Gap* (1992). http://www.psych.ucla.edu/Faculty/faculty.php?id=63&area=4

Appendix C – List of Expert Panelists

Janice Bradley –Mathematically Connected Communities, New Mexico State University, Las Cruces, New Mexico

Dianne DeMille – Math Coordinator, Orange County Department of Education, Costa Mesa, California

Kimberly Lightle – Director of Digital Libraries, College of Education & Human Ecology, Ohio State University, Columbus, Ohio

Glen Schuster – President, U.S. Satellite Laboratory and School Board Member, Rye, New York

Monica Sweet – Principal, Aspire Middle School, North Thurston Public Schools, Lacey, Washington

Ed Tobia – Project Director, Improving School Performance Program, Southwest Educational Development Lab, Austin, Texas

Kristin White – National Board Certified Teacher in Science/ Early Adolescence, Science Coach, Evergreen Public Schools, Vancouver, Washington

Appendix D – Expanded Methodology

Each type 1 research article was analyzed using the *Codebook for Standards of Evidence for Empirical Research* (http://www.mspkmd.net/pdfs/soe). This schema and methods for using it were developed by Horizon Research and the Education Development Corporation as part of their Knowledge Management and Dissemination project (KMD), funded by the Mathematics and Science Partnership (MSP) program of the National Science Foundation (NSF).

A Ph.D.-level analyst, trained in the standards and their use for evaluation of studies, spent five to eight hours inspecting each article; this level of effort may be substantially greater than that typically employed in the conduct of literature reviews. Titles of all 31 standards are listed below (Figure D-1). The standards are grouped into five domains.

Figure D-1. 31 Standards of Evidence (SoE) for empirical research.

Domains	Standards
A. Adequate Documentation of Project Activities	1. Research question and constructs 2. Research site 3. Sample demographics 4. Interventions and Implementation 5. Data collection
B. Internal Validity	6. Sample Bias 7. Response Bias 8. Attrition Bias 9. Missing Data Bias 10. Contamination 11. Validity Threats/Alternative Explanations Address Through Analysis 12. Validity Threats/Alternative Explanations Discussed 13. Investigator Bias/Reflexivity 14. Qualitative Descriptive Validity
C. Analytic Precision	15. Measurement Validity/Logic of Research Process (Unfounded Instruments) 16. Reliable Measures/ Trustworthy Techniques (Unfounded Instruments) 17. Appropriate and Systematic Analysis (Inappropriate Analysis) 18. Unit of Analysis Issues (Inappropriate Analysis)

	19. Power 20. Effect Size 21. Multiple Instruments/Sources of Evidence 22. Multiple Respondents 23. All Results
D. Generalizability/External Validity Determination	24. Findings for Whom 25. Generalizable to Population or Theory 26. Generalizable to Additional Contexts
E. Warrants for Claims	27. Limitations Presented 28. Decay and Delay of Effect 29. Efficacy 30. Conclusions/Implications Logically Drawn From Findings 31. Conclusions/Implications Grounded in Theory

In the standards of evidence codebook, each standard is accompanied by "questions and guidance to consider" to help the coder make decisions about ratings of quality (adequate, limited, poor). For many of standards, questions and guidance include content related to both quantitative and qualitative research. Figure D-2 shows the "questions and guidance to consider" for standard 2, research site.

Figure D-2. "Questions and guidance to consider" for Standard 2 in the MSP KMD *Codebook for Standards of Evidence for Empirical Research.*

Standard	**Questions and guidance to consider**
2. Research site	Were the research sites sufficiently described? Were the location(s) where the research took place sufficiently described given the nature of the study? For qualitative studies this typically requires more description than for quantitative studies, because situated description or "thick description" is often critical for qualitative research. Sufficient description includes stating things like the demographics of the community or school setting such as size, socioeconomic status, geographic location, financial resources, etc.

In addition to defining the standards and domains, the MSP KMD *Codebook for Standards of Evidence for Empirical Research* designates certain standards that have particular importance to a study's methodological integrity. Low ratings on any of these standards indicate that a study contains serious methodological flaws and are called "substantial limitations". If a study has substantial limitations, its contribution to the knowledge base will be greatly reduced.

Figure D-3. MSP KMD standards of evidence related to substantial limitations.

Domain	Indicator/Standard
B. Internal Validity	6. Sample Bias 7. Response Bias 8. Attrition Bias 9. Missing Data Bias 13. Investigator Bias/Reflexivity 14. Qualitative Descriptive Validity
C. Analytic Precision	15. Measurement Validity/Logic of Research Process (Unfounded Instruments) 16. Reliable Measures/ Trustworthy Techniques (Unfounded Instruments) 17. Appropriate and Systematic Analysis (Inappropriate Analysis) 18. Unit of Analysis Issues (Inappropriate Analysis)

Appendix E – List of Organizations Searched for PLC Statements

STEM Overall

- American Institutes for Research
- Biological Sciences Curriculum Study
- Education Development Center
- National Science Foundation
- Partnerships for Effective STEM Education
- SRI International
- STEM Education Caucus
- STEM Education Coalition
- TERC

Mathematics Education

- Association of Mathematics Teacher Educators
- National Council of Teachers of Mathematics

Science Education

- American Association of Physics Teachers
- American Chemical Society
- Association of Teachers of Science
- National Association of Biology Teachers
- National Earth Science Teachers Association
- National Middle Level Science Teachers Association
- National Science Teachers Association

Technology/Engineering

- International Technology Education Association

Educational Technology

- Computer Science Teachers Association
- International Society for Technology in Education
- Society for Information Technology and Teacher Education
- State Educational Technology Directors Association

Professional Development

- Association for Supervision and Curriculum Development
- Learning Points Associates
- National Staff Development Council (known as "Learning Forward" at time of print)
- SEDL

- West Ed

Policy/General

- Achieve
- All Things PLC
- American Federation of Teachers
- Center for Teacher Quality
- Council of Chief State School Officers
- Education Commission of the States
- National Comprehensive Center for Teacher Quality
- National Commission on Teaching and America’s Future
- National Education Association
- National Governor’s Association
- PBS Teacher Source
- Teacher Leaders Network

Publications

- *Phi Delta Kappan*
- *Ed Week*

Appendix F – Acronyms Used in Citations

Acronyms Used in Citations:

- (AAPT) American Association of Physics Teachers
- (AFT) American Federation of Teachers
- (ASCD) Association for Supervision and Curriculum Development
- (BSCS) Biological Sciences Curriculum Study
- (CTQ) Center for Teacher Quality
- (ECS) Education Commission of the States
- (EDC) Education Development Center
- (ISTE) International Society for Technology in Education
- (ITEA) International Technology Education Association
- (NCCTQ) National Comprehensive Center for Teacher Quality
- (NCTAF) National Commission on Teaching and America's Future
- (NCTM) National Council of Teachers of Mathematics
- (NEA) National Education Association
- (NSDC) National Staff Development Council (now known as "Learning Forward")
- (NSTA) National Science Teachers Association
- (Ontario) Ontario Ministry of Education, Expert Panel on Literacy and Numeracy Instruction for Students With Special Education Needs
- (PBS) Public Broadcasting Service's Teacher Source
- (SETDA) State Educational Technology Directors Association
- (SRI) SRI International