Attributes of Content-Focused Professional Learning Communities That Lead to Meaningful Reflection and Collaboration Among Math and Science Teachers

Marilyn Paula Carlson
Arizona State University

Chapter 6

Attributes of Content-Focused Professional Learning Communities That Lead to Meaningful Reflection and Collaboration Among Math and Science Teachers

Michael Oehrtman, Marilyn Carlson, and Jo Anne Vasquez

> Isolation buffers mediocrity and hides high performers from those who might learn from their modeling, consultation, and coaching. When practice is deprivatized, teachers visit one another's classrooms to observe master teaching, to coach each other, to mentor, and to problem solve in the living laboratory of instructional space.
>
> —Garmston and Wellman (1999)

Teaching reform efforts in the United States have often shown only short-term effects. Based on an analysis of video data from the Third International Mathematics and Science Study (TIMSS), Stigler and Hiebert (1999) argued that the reason for such limited success is that teaching is embedded in cultural practices whose pervasiveness is too great to overcome through standard professional development activities. They further argued that real change in school culture requires that teachers engage in career-long learning.

Long-term collaboration among teachers focused on student thinking and classroom practices is the basis of the successful and widely lauded practice of Japanese lesson study (Ma 1999; Shimizu 2002; Stigler and Hiebert 1999; Yoshida 1999). Pointing to the Japanese model, Stigler and Hiebert illustrated how teachers can collaborate to treat their classrooms as laboratories for developing, evaluating, refining, and disseminating new instructional ideas.

Lesson study members plan, implement, and study an actual lesson that is designed to achieve specific learning goals. Researchers commonly assist the teachers in collecting and analyzing videos of the lesson while it is being taught. The results inform further revisions to the lesson, then the lesson is taught again (Fernandez and Chokshi 2002; Lewis 2002b, 2002c; Lewis and Tsuchida 1998).

In addition to lesson study, other collaborative teacher groups have emerged around the country that are examining “records of practice” such as student work and classroom video (Ball and Bass 2002). Supporting the profession of teaching in a long-term scientific endeavor of reflecting on their practice shows significant promise for effecting real improvement in the U.S. education system.

Research suggests that among the best ways for teachers to improve practice is to spend more time not with their students but with their colleagues. According to Newmann and Wehlage (1995), “If schools want to…boost student learning, they should work on building a professional community that is characterized by shared purpose, collaborative activity, and collective responsibility among staff” (p. 37). The National Partnership for Excellence and Accountability in Teaching (Cibulka 2000) further suggested that teachers are more likely to change when they feel involved and supported in a collegial community of learners.

Regardless of the specific approach, all of these learning communities have in common involvement of groups of teachers to examine actual classroom data, determine what aspects of lessons have been effective, and incorporate subsequent revisions into their instruction. Although participating teachers typically express having a very positive experience, questions have been raised about how to ensure a high-quality conversation based on a deep understanding of the content (Lewis 2002a; Ma 1999). When observing a group of U.S. and Japanese elementary school teachers engaged in lesson study, Fernandez, Cannon, and Chokshi (2003) found that "the Japanese teachers displayed both a strong interest and remarkable insights into the development of content within a lesson. This was in sharp contrast to the American teachers who often did not think about these issues or, when prompted by their Japanese peers, lacked depth in explaining the content" (p. 178). Ma (1999) showed that shallow subject knowledge restricts teachers' capacity to promote conceptual learning among students. Catherine Lewis (2002c) noted that "lesson study alone does not ensure access to content knowledge" (p. 31). Findings such as these suggest that deep content knowledge should not be an assumed benefit of a learning community; rather, it is a goal that must be actively targeted in the community planning and implementation. DuFour and Eaker (1998) defined highly effective teacher collaborations as ones in which teachers gain conceptual and pedagogical knowledge and transfer that knowledge into observable and quantifiable improvements in their classroom practices. One approach for supporting the content focus of such effective collaborations is to have teachers explore challenging content, scientific inquiry, and problem solving in teams (LaChance and Confrey 2003; Westheimer and Kahne 1993). Unfortunately, American teachers have little opportunity for the types of *meaningful collaboration* with their peers as in efforts described above. By "meaningful," we emphasize the need for long-term, scientific engagement of issues of teaching and learning, such as that made possible by the Japanese lesson study model. We emphasize "collaboration" as one of the most essential goals for these communities to open teachers' classroom doors to the "critical colleagueship" of their peers (Lord 1994).

Recent moves by school districts in Arizona to provide scheduled time and resources for teachers to organize into small groups called professional learning communities (PLCs) have presented an opportunity to study effective practices and crucial support systems for establishing PLCs that engage in meaningful collaboration about their practice. After five years of developing and investigating PLCs in local schools, we have uncovered attributes that differentiate high-performing PLCs from lower-performing PLCs and have begun to uncover critical features for supporting and evaluating PLCs (Carlson, Oehrtman, Bowling, and Moore 2008). Our research has also identified detrimental beliefs about learning and teaching that can prevent teachers from translating positive experiences in PLCs into their own practice.

Background

Project Pathways is a Math and Science Partnership Program at Arizona State University supported by the National Science Foundation to implement and research teacher professional development in six large urban school districts in Arizona. Teams of STEM (science, technology, engineering, and mathematics) faculty, STEM education faculty, and secondary teachers partnered to create four graduate-level courses for secondary teachers. The courses were designed to support teachers in constructing deep understandings and connections of key STEM ideas and processes and engage teachers in authentic tasks that foster genuine inquiry about what is involved in knowing, learning, and teaching ideas in math and science and that support developing the habits of mind of a scientific thinker. A critical component of Project Pathways has been school-based PLCs for interdisciplinary groups of secondary mathematics and science teachers. PLC sessions engage teachers in

1. conceptual conversations about knowing and learning central ideas in secondary mathematics and science;
2. discussion and assessment of student thinking;
3. development of inquiry-based, conceptually focused lessons; and

4. meaningful reflection on the effectiveness of their instruction.

Focus on Content

The 1998 National Science Foundation report *Shaping the Future* calls for universities to channel more professional development support to the nation's teachers, especially to deepen their content knowledge. Far from having the "profound understanding" of content that characterizes effective teachers (Ma 1999), American teachers often have a shallow understanding of concepts and the connections among concepts that reveal STEM subjects as internally logical and coherent systems of knowledge and practice (Ball 1996; Cooney and Wilson 1993; Monk 1994; Norman 1992). This shallow understanding forces teachers to fall back on "stand and deliver" styles of teaching that emphasize rote memorization and calculational procedures. Rarely do American teachers engage students in deep-thinking explorations that develop critical minds capable of understanding challenging mathematical and scientific concepts (Stigler and Hiebert 1999). In a high-minority-population state like Arizona, superficial teaching of STEM subjects is especially damaging, because it disproportionately undermines the learning of minority and low-income students (Borman, Stringfield, and Rachuba 2000; Wenglinsky 1998).

Project Pathways courses and workshops have undergone three iterations of refinement and are now effective in promoting shifts in teachers' content knowledge for teaching precalculus-level mathematics and central ideas of physics, chemistry, geology, biology, and engineering. We use the Precalculus Concept Assessment (PCA) to assess foundational understandings and reasoning behaviors needed for success in beginning calculus and entry-level courses in science and engineering (Carlson, Oehrtman, and Engelke 2008). Although concepts assessed by the PCA provided a unifying thread through all courses and workshops, we also used discipline-specific instruments such as the Force Concept Inventory (FCI; Hestenes, Wells, and Swackhamer 1992) and the Geoscience Concept Inventory (GCI; Libarkin and Anderson 2005). The research findings have confirmed our hypothesis that translating this new knowledge to an individual's teaching practice requires more than just new understanding of the mathematics or science they teach. It also requires opportunities for teachers to engage in meaningful collaboration about knowing, learning, and teaching mathematics and science, including time and support to redesign, study, and revise new curriculum sequences for selected topics.

The Intervention

The structure of Project Pathways offers an opportunity for high school math and science teachers to work as teams in a collaborative culture of professional development both as students in Project Pathways courses and as teachers in PLCs. In doing so, teachers from STEM disciplines experience modeling of quality inquiry-based math and science pedagogy, not only by the course instructional leaders, but also by their own team members. Although the nature of math-science integration and implementation of enhanced knowledge, understanding, and skills differs in math and science classroom practice, teachers acquire an underlying understanding of the complementary nature of mathematics and science implicit in the pedagogy modeled in the project's courses. In particular, mathematical problem solving, the scientific method, and engineering design all involve the following processes:

- observing and orienting oneself to the nature, elements, and structure of a situation;
- generating hypotheses or potential solution paths through analogical reasoning and rapid mental evaluation;

- conducting selected tests or implementing strategies; and
- evaluating effectiveness and reiterating the process if necessary.

This linkage and integration of mathematics and science has the potential for synergistic impact on student learning in both subjects. The project's four courses facilitate the connections between mathematics, science, and engineering by highlighting these general processes in the teachers' own reasoning as they learn new content, then asking them to apply the same scientific reasoning to issues of student thinking and to their teaching practices. The accompanying PLCs support teachers in revising their own teaching practices and evaluating the outcomes in a scientific manner.

Embedded in the four Project Pathways courses are the project's primary focus areas:

- creating a sustainable culture of collaboration of math and science teachers in PLCs;
- improving teachers' content knowledge for teaching secondary mathematics and science, including a focus on ideas of rate of change, growth patterns in covarying quantities, and mathematical functions for modeling phenomena;
- improving teachers' scientific reasoning, engineering design, and mathematical problem-solving abilities;
- improving teachers' ability to see content connections in secondary mathematics and science and to adapt curriculum to promote these connections in their classrooms; and
- improving teachers' ability to reflect on the quality of their curriculum in relation to student learning.

The Pathways Courses

The four primary courses developed for Project Pathways are Functions and Modeling; Connecting Physics, Chemistry and Mathematics; Connecting Biology, Geology and Mathematics; and Connecting Engineering, Science and Mathematics. Science and math teachers at each school completed the courses together in their own schools in cohorts with no more than 30 members. Each course ran for 15 weeks during the academic year and was provided tuition-free. The partner schools requested that classes meet weekly during the semester, with each course having at least 60 contact hours between faculty and teachers (45 hours in course work and 15 hours in learning communities). The instruction in the courses promoted inquiry and meaning making to encourage participating teachers to adopt this focus in their own instruction with secondary students. The curriculum for all four courses promoted use of STEM behaviors and the ability to draw on and use the concept of function as a mathematical tool in scientific investigations and engineering design.

Course and PLC Norms

During each course, the instructor (a university faculty member) modeled and promoted *speaking with meaning*, a way of communicating that was negotiated as a goal during the first day of the course. In light of previous observations that revealed poor-quality discourse during the class and the PLCs, the instructor held a class discussion on “rules of engagement” that would be beneficial to improve communication and promote teacher development during the course and the PLC sessions. The notion of speaking with meaning conveyed that teachers would attempt to speak so that their words carry meaning to the listener, and are thus conceptually based; be specific by referencing quantities and avoiding the use of vague pronouns in explanations when appropriate; and explain and justify solution approaches so that the rationale for the approach can be understood by others. The rules of engagement also included such guidelines as exhibiting intellectual integrity (e.g., basing conjectures on logic, not pretending to understand when one doesn't really understand), respecting the learning process of colleagues, and attempting to make sense of colleague's meanings. Investigations revealed that the facilitators in cohort 1 had difficulty modeling and reinforcing these behaviors. This led to our developing facilitator workshops designed to support the facilitators in modeling speaking with meaning and promoting meaningful communication among members of a PLC.

The PLC Facilitator and PLC Sessions

Each PLC had an assigned peer leader who was charged with facilitating discussions during the PLC meetings. The facilitators were selected based on their leadership abilities as recommended by their district math/science coordinator and were initially trained during four 6-hour summer workshops. In addition to the weekly meetings, the facilitators also attended three 3-hour workshops during the semester. These workshops focused on developing specific attributes for facilitation that included their ability to ask questions to promote conceptual explanations and conversations. They were also supported in improving their facilitation ability during weekly coaching sessions with project staff. The workshop leaders engaged the PLC facilitators in a series of activities designed to improve their abilities to both listen to the quality of mathematical and scientific explanations with respect to their conceptual nature and learn to pose questions that promoted reflection on what is involved in understanding, learning, and teaching specific science and mathematics concepts. For instance, one activity included viewing and discussing videos of students as they explained their thinking when responding to conceptual tasks. This activity asked the facilitators to discuss what they could infer about student understandings from the video and their rationale behind these inferences.

Senior project personnel led weekly facilitator coaching sessions with the facilitators. During each coaching session, the coach asked questions about the facilitation behaviors observed in the video of each facilitator during their previous PLC sessions to promote reflection about the quality of various PLC interactions. As the coach viewed these videos with the research team before the coaching meetings, they discussed the facilitators' effectiveness in promoting and enacting speaking with meaning about issues of knowing, learning, and teaching the content that was the focus of that PLC agenda. These discussions provided opportunities for the coach to address specific interactions during the coaching meetings that either promoted or inhibited meaningful discourse among members of a PLC.

The coach's strategies for promoting reflection about PLC interactions progressed from general discussions to making specific prompts to each PLC facilitator. During the first few coaching sessions, the coach discussed positive moves that she and the research team were noticing in hopes that the PLC facilitators who were less effective would begin to adopt the more effective strategies. As one example, she noted that when PLC members appeared to be speaking past each other, the facilitator of the PLC prompted the PLC members to put a written product on the whiteboard and encouraged the PLC members to speak about the ideas of the problem. The facilitator coach also gave general suggestions that she thought might promote positive facilitator moves, such as making an effort to listen to the meanings that the PLC members were communicating and trying to ask questions based on these meanings. As the PLC coach sensed that the facilitators were becoming more comfortable in their role as a facilitator, she became more direct with each of the PLC facilitators about behaviors that were less effective.

Results of Research on Project Pathways PLCs

The professional development implementation and the research design for Project Pathways was guided by previous research studies that investigated and articulated the process of learning, understanding, and using the concept of function (Carlson 1998; Oehrtman, Carlson, and Thompson 2008) and attending to the covarying patterns in phenomena (Carlson, Jacobs, et al. 2002). Three discipline-specific frameworks that articulate the processes of STEM inquiry (Atman et al. 2003; Carlson and Bloom 2005; Lawson 2001) informed the development of course modules and classroom instruction and served as a lens for analyzing discourse patterns in the course and PLCs.

Teachers and district leaders in the Project Pathways partnership overwhelmingly cited their participation in these PLCs as the most rewarding and effective component of the project. Pathways research teams have generated extensive data corroborating these anecdotal claims and have uncovered critical variables that affect the functioning of these PLCs. We have identified crucial components of PLC formation and support that lead to inquiry and engagement about issues of student thinking and learning. Our analysis of qualitative data on teachers' engagement in their PLCs resulted in the emergence of three central categories of *process behaviors* generalizing the discipline-specific frameworks for STEM inquiry and three categories of *dispositional behaviors* related to their approach to discourse. We have also observed that the PLC facilitator is a key variable in promoting meaningful discourse among the PLC members.

Process Behaviors of PLC Members

Analysis of video data from PLC sessions revealed specific behaviors and dispositions of the PLC members that led to quality discourse about knowing, learning, and teaching mathematics and science. The three general process behaviors are productive engagement, effective use of conceptual resources, and persistence and reflection.

- *Productive engagement* is characterized by the PLC members exploring or clarifying some issue that is problematic to the PLC members, and all members of the PLC are encouraged to participate.
- *Effective use of conceptual resources* is characterized by the PLC members intentionally seeking and selecting relevant concepts or ideas to advance their discussions. The PLC members are alert to the possibility that they may have gaps in their collective understanding and may need to seek information from print or online resources or individuals not in the PLC.
- *Persistence and reflection* implies that the PLC members stay engaged until a problem is resolved; this is followed by their evaluating the quality of their solution and reflecting on the effectiveness of the tools they applied.

Table 6.1 provides productive and unproductive examples of these PLC process behaviors.

Table 6.1. Process Behaviors

Category	Productive Examples	Unproductive Examples
Productive engagement	Members engage in exploring a common problematic issue, clarify the nature of the problem, and encourage participation of all members.	Members work routinely through the agenda without reflective engagement, are not focused on a common issue, and exclude others from participating.
Conceptual resources	Members are intentional in their selection of conceptual resources to apply to a problem, apply appropriate and powerful ideas, and seek appropriate external assistance when there is a gap in their collective understanding.	Members choose inappropriate content-based tools, are not able to properly apply tools appropriately, and regularly offer irrelevant or incorrect statements.
Persistence and reflection	Members stay engaged until a problem is resolved, evaluate the quality of their solution, and reflect on the effectiveness of the tools they applied.	Members offer suggestions and ideas without evaluation of appropriateness, are satisfied with solutions without understanding, and quickly give up when they are not successful.

Dispositional Behaviors of PLC Members

Our study of the communication patterns of the PLCs revealed that the initial level of discourse and the quality of the communication were not very high. Members of the PLCs were often focused on performing procedures, and their explanations often focused on these procedures as opposed to the underlying concepts of the problem (see Table 6.2). We observed that conversations between two PLC members often did not result in an exchange of ideas, and the teachers were observed talking past each other with little discussion of student learning and what is involved in understanding mathematics and science concepts.

Table 6.2. Dispositional Behaviors

Category	Productive Examples	Unproductive Examples
Conceptual orientation	Members clarify ideas, focus on meanings in mathematical and scientific activity, and identify and resolve ambiguity.	Members focus on procedures without connection to meaning, offer answers as sole evidence of student understanding, and use jargon without clarification.
Intellectual integrity	Members provide rationale for claims, exhibit honesty about lack of understanding, and show willingness to challenge others and be challenged.	Members avoid putting their thinking on the table, defer to authority, and avoid confronting each other on incorrect or inconsistent statements.
Coherence	Members seek and establish connections among ideas and topics, express ideas using multiple representations, and generalize conclusions to other settings or find limiting conditions.	Members treat concepts as isolated and unrelated, fixate on single ideas, and are not open to other solutions.

As the semester progressed, teachers' attempts to speak with meaning emerged as a stronger social norm. During PLC sessions, the teachers began attempting to justify their responses with more than just procedural explanations. In these cases, the members often used the context of the problem in their explanations and made observable attempts to provide a rationale for their approach; however, their explanations were often insufficient in that they did not include a coherent justification for their solution approach.

As PLC facilitators further fostered the emergence of the social norms for what would constitute a sufficient explanation or justification, teachers began to hold each other accountable for providing more meaningful explanations, and hence establish criteria for speaking with meaning.

Over the course of the semester, they began demanding that justifications be conceptual and that individuals include a clear articulation of the quantities, relationships, and implications inherent in the problem or context under discussion.

Beliefs and Attitudes

Use of quantitative instruments, such as the Views About Mathematics Survey (VAMS; Carlson 1997) and the Views About Science Survey (VASS; Halloun 1997; Halloun and Hestenes 1998), revealed shortcomings in teachers' views about the methods of doing mathematics and science that informed our refinement of the course. However, early in the project we discovered that these instruments did not sufficiently account for many of the key objectives of the project (especially related to the integration of STEM disciplines) and perceived barriers to implementing reform that were exhibited by the teachers. In our analysis of video data, the coding of these beliefs converged around four categories as outlined in Table 6.3, including factors of resistance, beliefs about STEM learning, beliefs about STEM teaching, and confidence and perceived ability in STEM disciplines.

Table 6.3. Categories of Belief

Category	Examples
Factors of resistance	"The pace at which I must cover material does not allow me to teach ideas deeply." "My school administrators do not value my efforts to get students to understand ideas deeply."
Beliefs about STEM learning	"Making unsuccessful attempts when working on a mathematics problem is an indication of one's weakness in mathematics." "Learning happens when students are provided opportunities to construct meaning and make connections."
Beliefs about STEM teaching	"It is important to understand what a student is thinking when s/he asks a question." "The primary goal of my exams is to assess if my students can memorize facts and carry out procedures like ones required for completing the homework."
Confidence and perceived ability in STEM disciplines	"I feel prepared to create learning opportunities for my students that promote connections between mathematics and science." "I have a clear understanding of how central ideas of my courses develop in students."

Note: STEM = science, technology, engineering, and mathematics.

Decentering and Facilitator Strategies

Tracking the facilitation abilities of PLC facilitators revealed interaction patterns between the facilitator and other PLC members that influenced the quality of inquiry among the group. Our analyses also revealed that the degree to which the facilitator was willing and able to build models of other members' thinking when interacting with them influenced the meaningfulness of the exchange. We found that most facilitators gradually improved in both of these abilities as a result of coaching by project personnel.

To actively facilitate teachers in a PLC requires that the facilitator “place” her- or himself in the other members’ shoes. Placing oneself in another’s shoes is a classic example of what Piaget (1955) identified as *decentering*, or the attempt to adopt a perspective that is not one’s own. Steffe and Thompson (2000) extended Piaget’s idea of decentering to the case of interactions between teacher and student (or mentor and protégé) by distinguishing between ways in which one person attempts to systematically influence another. In that process, each person acts as an observer of the other, creating models of the other’s ways of thinking.

The construct of decentering implies that it is important for a facilitator to both remain attentive to the fact that each member of the group has a rationality that is completely her or his own and attempt to discern that rationality. The activity of decentering is important to a PLC setting, but it is also applicable to a classroom. If one is truly concerned with student learning, it is necessary to build models of students’ thinking and base further interactions on these models. Analysis of the facilitators revealed four observable manifestations of decentering, with a fifth manifestation hypothesized from our theoretical perspective (Table 6.4).

Table 6.4. Facilitator Decentering Moves (FDMs) in a Professional Learning Community (PLC)

Facilitator Decentering Moves	
Code	**Facilitator Action**
FDM 1	The facilitator shows no interest in understanding the thinking or perspective of a PLC member with which he/she is interacting.
FDM 2	The facilitator takes actions to model a PLC member's thinking, but does not use that model in communication with the PLC member.
FDM 3	The facilitator builds a model of a PLC member's thinking and recognizes that it is different from his/her own. The facilitator then acts in ways to move the PLC member to his/her way of thinking, but does so in a manner that does not build on the rationale of the other member.
FDM 4	The facilitator builds a model of a PLC member's thinking and acts in ways that respect and build on the rationality of this member's thinking for the purpose of advancing the PLC member's thinking and/or understanding.
FDM 5	The facilitator builds a model of a PLC member's thinking and respects that it has a rationality of its own. Through interaction, the facilitator also builds a model of how he/she is being interpreted by the PLC member. He/she then adjusts her/his actions (questions, drawings, statements) to take into account both the PLC member's thinking and how the facilitator might be interpreted by that PLC member.

We observed that the facilitator decentering moves that had the greatest implications for the quality of the PLC discourse occurred while modeling or encouraging productive process and dispositional behaviors as outlined earlier in this chapter. Examples of the effective facilitator strategies we observed are provided in Table 6.5.

Table 6.5. Facilitator Strategies

Examples of Strategies for Fostering Process Behaviors
IV. *Productive engagement*: Facilitator asks questions to cause disequilibrium about an important topic, focus all participants on a common issue, and encourage reflection.
V. *Conceptual resources*: Facilitator possesses and directs the use of appropriate content and pedagogical tools or manages the discussion to capitalize on the expertise of each member.
VI. *Persistence and reflection*: Facilitator encourages the members to evaluate their solutions and assess whether they have made their reasoning clear to the group.
Examples of Strategies for Fostering Dispositional Behaviors
I. *Conceptual orientation*: Facilitator refocuses discussions about how to "do" problems toward the meanings of quantities and procedures, and requests and models speaking meaningfully.
II. *Intellectual integrity*: Facilitator asks members to provide rationale for their thinking, points out inconsistencies, and checks with members about what they do and do not understand.
III. *Coherence*: Facilitator asks for multiple representations and guides the discourse in the group to compare and extend ideas and consider subtleties, exceptions, and alternative explanations.

Both the science and math facilitators initially showed little tendency to decenter. At the beginning of the course and in their early PLC sessions they frequently expressed that they were accustomed to viewing teaching as carrying out procedures or explaining how to get answers to specific types of problems. Both their direct comments and discussions when completing tasks revealed that they were uncomfortable in participating in professional development that focused on making meaning of science and mathematics ideas. They often expressed some frustration in being asked to reason and explain their thinking about fundamental ideas such as force, pressure, and rate of change. However, as the course and PLC sessions progressed they began to express appreciation of efforts to hold them accountable to think deeply about the processes and connections needed to understand and use central ideas in the curriculum that they teach. Through the facilitator workshops and coaching, most of the facilitators improved their ability to decenter over the course of the year. These facilitators appeared to value efforts to understand others' thinking and be motivated to engage in discourse to uncover meaning of the ideas under discussion. As their ability to decenter improved, their questioning improved and the quality of the discourse among members of the PLC became more meaningful.

Even for facilitators with weak mathematical or scientific backgrounds, the discussions in their PLCs became more meaningful over the year, although these improvements did not result from the facilitators decentering during interactions with their colleagues. In fact, weak mathematical or scientific understandings, as revealed by classroom and performance data, appeared to limit their ability to decenter in the context of discussions about mathematical and scientific ideas. Analysis of video data from these PLCs revealed that making strategic moves would enhance a mathematically or scientifically weak facilitator's effectiveness. For example, the facilitator might ask questions that promote reflection and decentering by other members of the PLC, as they are encouraged to interact with each other. The quality of the exchanges that followed such moves to facilitate discussions among the PLC members appeared to be affected by the decentering abilities and depth of mathematical and scientific understanding of other members of the PLC. Thus, although a mathematically or scientifically weak facilitator may not be able to understand or follow all discussions, he or she may still be effective by posing general questions to engage members of the PLC in making meaning of ideas and others' thinking.

The Role of the District and School Administrators

The support of participating school principals and math and science department chairs has been critical for sustaining Project Pathways interventions. Since cohort 3 had at most 40% of the math and science teachers from a given school, we anticipated obstacles to scaling up the PLCs to all teachers within a school, and as interest emerged among teachers to scale up Pathways interventions within a school, we met some resistance. As one example, 8 (out of 31 math and science teachers) from a particular school became highly motivated to institutionalize the PLCs so that they could continue them at their school with all of their colleagues participating. Pathways project leadership met with the school principal, the math department chair, and the science department chair, and although there was initial interest, the math department chair later determined that it would be logistically difficult to arrange teacher schedules so that PLCs could meet during the school day. He also revealed that he thought Pathways was only needed for younger teachers in his department. His resistance led to the school discontinuing PLC meetings and their choosing to not have the project offer courses or workshops to other teachers in the school. This situation may have been avoided had we required that prior to infusing funds in a particular school the principal agree to scale up interventions that were valued by a majority of the teachers.

After this event, the project Principal Investigator (PI) contacted the project's funder to request permission to select a few Pathways schools for cohort 4. The goal was to begin cohort 4 intervention with a school in which the principal, math department chair, and science department chair were all supportive of Pathways courses and PLCs. In negotiating strategies with the principal for obtaining 100% participation from the math and science teachers in his school, we determined that not all teachers were able to enroll in the graduate course sequence. This resulted in our deciding to hold monthly three-hour workshops, with similar content focus as the courses, for teachers who were unwilling or unable to participate in the full course. The project PI also met with the superintendent and other district curriculum administrators to discuss Pathways goals and to communicate to them what school and district commitments would be needed to adopt that school as a Pathways-designated school. The response and support from these administrators resulted in them doing the following:

- agreeing to rearrange the school schedule so that content-focused PLCs could meet for one hour each week during the school day,
- agreeing to pay PLC facilitators an extra stipend and to pay all teachers for their time in participating in Pathways PLCs, and
- hiring substitutes so that teachers not enrolled in the course could participate in the monthly workshops during the school day.

We are about one semester into the intervention for this cohort and are appreciative of the support we are receiving from the principal of this school. He expressed to the project PI that he has been visiting his teachers' classes and is already seeing a difference in the level of student engagement and focus on teaching relevant ideas in classrooms in his school.

Summary

Transforming the professional development culture and teaching practices of science and mathematics teachers within a school requires sustained efforts and a supportive school environment. Courses or experiences that engage teachers in inquiry and improve teachers' understanding of the content they teach are a critical variable for the transformation of teaching practices. Shifts in teachers' *content knowledge for teaching* enables them to examine student thinking and develop meaningful lessons for students. However, local factors (e.g., district or departmental exams, the school curriculum) often present obstacles that must be navigated as teachers work to improve their teaching practice.

A facilitator who listens to the meanings of other PLC members and subsequently probes and promotes reflection and meaning making can have a positive impact on the quality of the discourse in a PLC. Promoting genuine inquiry about issues of knowing, learning, or teaching are productive to the extent that the facilitator and other PLC members possess the conceptual tools and habits of persisting and reflecting. PLCs that have members who strive for coherence and connections and spontaneously provide a rationale for claims are also more likely to exhibit quality discourse about teaching and learning. When starting PLCs within a school, it is important to select PLC facilitators who value these process and dispositional behaviors. Initial workshops that support PLC facilitators in attending to the thinking and learning of their colleagues can also substantially increase the effectiveness of a PLC facilitator.

Reflection Questions

- To what extent do math and science teachers in your context currently interact? If you plan to integrate math and science PLCs, what benefits do you expect teachers to gain from interdisciplinary collaboration? How might the Pathways perspective of inquiry as a generalization of mathematical problem solving, scientific inquiry, and engineering design be employed in your context?
- What lessons can you draw from the Pathways implementation to help teachers see student thinking and their own teaching practices as problematic and worthy of inquiry?

How can you support teachers to make data-driven claims and decisions and evaluate the effectiveness of their actions?

- What expectations for interactions among teachers in PLCs do you find most critical to foster the Pathways vision of meaningful inquiry? What lessons from the Pathways PLCs might help teachers to overcome the intense social pressure to resist challenging each other and to hold each other accountable for speaking with meaning and exhibiting intellectual integrity? How can you ensure the quality of content and pedagogical discourse in the PLCs?
- What pressures do teachers in your context face that may result in resistance to the objectives and practices of productive PLCs? What lessons from the Pathways implementation may help you to confront potentially counterproductive beliefs?
- What options for PLC facilitation exist in your context? What support is necessary to help facilitators decenter and foster productive process and dispositional behaviors in their PLCs?

References

Atman, C., R. Adams, M. Cardella, J. Turns, S. Mosborg, and J. Saleem. 2007. Engineering Design Processes: A Comparison of Students and Expert Practitioners. *Journal of Engineering Education* 96 (4): 359 -379

Ball, D. L. 1996. Teacher learning and the mathematics reforms: What do we think we know and what do we need to learn? *Phi Delta Kappan* 77 (7): 500-508.

Ball, D. and H. Bass. 2002. Professional development through records of instruction. In *Studying classroom teaching as a medium for professional development: Proceedings of a U.S.–Japan* *workshop*, eds. H. Bass, Z. P. Usiskin, and G. Burrill, 79-89. Washington DC: National Academy Press.

Borman, G., S. Stringfield, and L. Rachuba. 2000. *Advancing minority high achievement: National trends and promising programs and practices*. New York: College Board.

Carlson, M. 1997. The development of an instrument to assess students' views about the methods and learnability of mathematics. In *Proceedings of the 19th Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* 2: 395–403. Columbus, OH: The Ohio State University.

Carlson, M. 1998. A cross-sectional investigation of the development of the function concept. In *Research in Collegiate Mathematics Education. III. CBMS Issues in Mathematics Education,* eds. A. H. Schoenfeld, J. Kaput, & E. Dubinsky, 114-162. Providence, RI: American Mathematical Society.

Carlson, M., and I. Bloom. 2005. The cyclic nature of problem solving: An emergent multidimensional problem-solving framework. *Educational Studies in Mathematics* 58: 45–75.

Carlson, M., S. Jacobs, E. Coe, S. Larsen, and E. Hsu. 2002. Applying covariational reasoning while modeling dynamic events: A framework and a study. *Journal for Research in Mathematics Education* 33: 352–378.

Carlson, M., M. Oehrtman, and N. Engelke. (under review). The precalculus concept assessment (PCA) instrument: A tool for assessing reasoning patterns, understandings and knowledge of precalculus level students.

Carlson, M., M. Oehrtman, S. Bowling, and K. Moore. (under review). The emergence of decentering in facilitators of professional learning communities of secondary mathematics and science teachers.

Cibulka, J. 2000. *Practitioners' guide to learning communities. The creation of high-performance schools through organizational learning*. RFP-97-0101, Project 4.4.1. Washington, DC: National Partnership for Excellence and Accountability in Teaching.

Cooney, T., and M. Wilson. 1993. Teachers' thinking about functions: Historical and research perspectives. In *Integrating research on the graphical representation of functions*, eds. T. A. Romberg, E. Fennema, and T. P. Carpenter, 131–138. Hillsdale, NJ: Lawrence Erlbaum.

DuFour, R., and R. Eaker. 1998. *Professional learning communities at work: Best practices for enhancing student achievement.* Bloomington, IN: National Educational Service.

Fernandez, C., and S. Chokshi. 2002. A practical guide to translating lesson study for a U.S. setting. *Phi Delta Kappan* 84 (2): 128–134.

Fernandez, C., J. Cannon, and S. Chokshi. 2003. A U.S.–Japan lesson study collaboration reveals critical lenses for examining practice. *Teaching and Teacher Education* 19 (2): 171–185.

Garmston, R. J., and B. M. Wellman. 1999. *The adaptive school: A sourcebook for developing collaborative groups*. Norwood, MA: Christopher-Gordon.

Halloun, I. 1997. Views about science and physics achievement: The VASS story. In *The changing role of physics departments in modern universities: Proceedings of ICUPE*, eds. E. Redish and J. Rigden, 605–614. College Park, MD: American Institute of Physics Press.

Halloun, I., and D. Hestenes. 1998. Interpreting VASS dimensions and profiles. *Science and Education* 7(5).

Hestenes, D., M. Wells, and G. Swackhamer. 1992. Force Concept Inventory. *The Physics Teacher* 30: 141–158.

LaChance, A., and J. Confrey. 2003. Interconnecting content and community: A qualitative study of secondary mathematics teachers. *Journal of Mathematics Teacher Education* 6: 107-137.

Lawson, A. E. 2001. Using the learning cycle to teach biology concepts and reasoning patterns. *Journal of Biological Education* 35 (4): 165–169.

Lewis, C. 2002a. Does lesson study have a future in the United States? *Journal of Education and Human Development* 1: 1–23.

Lewis, C. 2002b. *Lesson study: A handbook of teacher-led instructional change*. Philadelphia: Research for Better Schools.

Lewis, C. 2002c. What are the essential elements of lesson study*? California Science Project Connection* 2 (6): 1-4.

Lewis, C., and I. Tsuchida. 1998. A lesson is like a swiftly flowing river: Research lessons and the improvement of Japanese education. *American Educator* (Winter): 14–17, 50–52.

Libarkin, J.C., and S. W. Anderson. 2005. Assessment of learning in entry-level geoscience courses: Results from the Geoscience Concept Inventory. *Journal of Geoscience Education* 53: 394–401.

Lord, B. 1994. Teachers' professional development: Critical colleagueship and the role of professional community. In *The future of education: Perspectives on national standards in America*, ed. N. Cobb. New York: College Entrance Examination Board.

Ma, L. 1999. *Knowing and teaching elementary mathematics*. Mahwah, NJ: Lawrence Erlbaum.

Monk, D.H. 1994. Subject area preparation of secondary mathematics and science teachers and student achievement. *Economics of Education Review* 13 (2): 125–145.

National Science Foundation (NSF), Committee for the Review of Undergraduate Education. 1998. *Shaping the future: New expectations for undergraduate education in science, mathematics, engineering, and technology.* Arlington, VA: NSTA.

Newmann, F. M., and G. G. Wehlage. 1995. *Successful school restructuring: a report to the public and educators.* Washington, DC: American Federation of Teachers. (ERIC Document Reproduction Service no. ED387925).

Norman, A. 1992. Teachers' mathematical knowledge of the concept of function. In *The concept of function: Aspects of epistemology and pedagogy*, eds. G. Harel and E. Dubinsky, 215–232. MAA Notes Vol. 25.

Oehrtman, M., M. Carlson, and P. W. Thompson. 2008. Foundational reasoning abilities that promote coherence in students' function understanding. In *Making the Connection: Research and Practice in Undergraduate Mathematics, MAA Notes Volume 73*, eds. M. Carlson and C. Rasmussen, 27-41. Washington, DC: Mathematical Association of America.

Piaget, J. 1955. *The language and thought of the child*. New York: Meridian Books.

Shimizu, Y. 2002. Lesson study: What, why, and how? In *Studying classroom teaching as a medium for professional development: Proceedings of a U.S.–Japan workshop,* eds. H. Bass, Z. P. Usiskin, and G. Burrill, 53-57. Washington, DC: National Academy Press.

Steffe, L. P., and P. W. Thompson. 2000. Interaction or intersubjectivity? A reply to Lerman. *Journal for Research in Mathematics Education* 31 (2): 191–209.

Stigler, J., and J. Hiebert. 1999. *The teaching gap: Best ideas from the world's teachers for improving education in the classroom.* New York: Free Press.

Wenglinsky, H. 1998. *Does it compute? The relationship between educational technology and student achievement in mathematics.* Princeton, NJ: Educational Testing Service.

Westheimer, J., and J. Kahne. 1993. Building school communities: An experience-based model. *Phi Delta Kappan* 75 (4): 324–328.

Yoshida, M. 1999. Lesson study [Jugyokenkyu] in elementary school mathematics in Japan: A case study. Paper presented at the annual meeting of the American Educational Research Association, Montreal.