Meeting Teachers' Professional Development Needs

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The Context for Change

Our Local Systemic Change project, Critical MASS, began with two simple, yet challenging premises. First, if we wanted to improve science and mathematic learning for all students, we needed to have an impact on all teachers. Improving mathematics and science learning for all students would require the sustained engagement of all teachers. Therefore, we decided that the primary venues for professional development had to occur during the school day and not be voluntary. Second, we believed that meaningful improvement would require deeper understanding of content and children's thinking, changing the culture, and ongoing classroom level support.

When we started to think about applying for a National Science Foundation grant in Hudson, Massachusetts in 1998, we had already initiated the implementation of *Investigations* and *FOSS* at the elementary level and *CMP, FOSS* and *SEPUP* at the middle school level. Previously, a core group of teachers, led by an extraordinarily supportive superintendent, met and took courses in active investigative mathematics instruction. The district leadership and school board were firmly committed to a comprehensive systemic investment to improve math and science. We began with a small pilot of *Investigations* among several volunteer elementary teachers. The size of this volunteer group grew over several years until, *Investigations* was adopted as a district wide program. Almost simultaneously, a district-wide committee of teachers, administrators, and a scientist examined a variety of science programs, conducted a classroom pilot, and then selected *FOSS* as its core elementary science program. Following that, *CMP* and a matrix of science programs developed with NSF funding were selected and initiated in middle school. Because we engaged teachers in initial professional development related to the content and use of these curriculum materials, we were looking for support for "next steps."

With these notions in mind, we found a partner at a similar stage of development and intention in Fitchburg, a neighboring school district. As we talked and planned for the challenges of addressing both science and mathematics from kindergarten through grade 8, several key goals emerged:

- ✓ Increase teachers' content knowledge
- ✓ Increase teachers' pedagogical content knowledge
- ✓ Increase the level of collegial dialogue and reflection
- ✓ Increase instructional synergy between mathematics and science

In the pages that follow, I will tell the story of how we defined, listened to, and responded to the professional development needs of a diverse group of teachers at various stages of career, knowledge, development, interest, willingness, and philosophical agreement with respect to these goals. Two lessons stand out. The first is the importance of the local and general cultural context of teaching. The second is the differential needs of required and volunteer participants. Because, Hudson and Fitchburg are different both demographically and in administrative structure, I will keep the story simpler, by focusing on Hudson, the cultural context I know best.

I write this as the Principal Investigator and Director of Critical MASS, as well as the Elementary Mathematics and Science Director in Hudson. In preparing for writing, I spoke with my co-investigators, curriculum directors, our mathematics professional developer, our evaluator, and teachers. This reflection, a look back in order to move forward, has been very helpful for all of us. I hope that we can share some insights that will support others on a similar path and those about to embark on the journey.

Hudson is a socio-economically and ethnically diverse community. The Hudson Public Schools consists of a kindergarten center, three elementary schools, a middle school and a high school. The preschool

through grade twelve student population is about 2800 students. Thirty-five percent of the student population is Portuguese with many coming from Brazil and the Azores, as well as mainland Portugal. Over ten percent of the students come from non-English speaking homes. The student population eligible for free or reduced lunch ranges from twelve to over twenty percent in our elementary and middle schools.

Hudson is somewhat unique in its high degree of administrative stability. Dr. Sheldon Berman has been our superintendent for thirteen years and this is my eighth year as a curriculum director. We have had an extraordinarily supportive school board. Fortunately, we have had stability and a common vision among our leadership. As a result, we have been able to concentrate on the needs of teachers and students without the distractions that typically come in the absence of these essential components of reform.

Starting Assumptions and Plan

Our premise for requiring professional development for all and our self-definition as a "next-steps" project rested on several key assumptions. We proposed that significant impact on learning would be realized when we pushed beyond initial stages of implementation of high-quality, inquiry-based instructional materials. We knew that, with our support, teachers would need to refine curriculum and instruction to be responsive to developing student understanding. This required a substantial investment in enriching teachers' content and pedagogical-content knowledge. We believed that this would be accomplished with four key supports in place.

1) We developed a five-year course of study that addressed the major concepts to be taught at each grade level, spanning the domains of science and mathematics. These were to be delivered in grade level sessions during the school day on three full days each year. Principals agreed to release teachers and to provide substitutes. Though this has been a continual challenge, they have consistently done so for five years. We recruited a mix of curriculum developers, developer-trained experienced teacher leaders, and university-based science and math educators to deliver the workshop content. Our model for these sessions was derived from the Developing Mathematical Ideas (DMI) project. The structure of most workshops included adult content-based investigations, examination and analysis of student work and/or observation of classroom video, and discussion about instructional implications.

2) We hired a full time mathematics staff developer whose primary responsibility was to spend time in classrooms supporting teachers. The math staff developer, who came to us from another district, had significant classroom experience with *Investigations*, as well as leading professional development and developing curriculum. We expected the consultancy provided through each of the classroom visits to vary based on the experience, knowledge and instructional orientation of the teacher. To some extent, we knew these visits would almost require an individual professional development plan for each teacher. We also expected, and have subsequently found, that this personal one-on-one interaction would be the single most important professional growth component of the project.

3) We knew that the development of a core of teacher leaders would be essential to the development and sustainability of our goals. However, we decided to proceed slowly and with caution. We decided to avoid the early "anointing" of teacher leaders based on our own preconceptions. Instead, we waited for a year into the project for leaders to emerge. Since, we had hired a full-time mathematics staff developer and had full time elementary math and science directors, we were not dependent on teacher leaders for direct day-to-day support in the classroom. We defined the role of "Teacher Facilitators" primarily as advocates for change. Our Teacher Facilitators were those teachers who were willing to make an extra investment in their own learning. They were, in a sense, cultural ambassadors who were willing, over time, to be public about their interest in digging deeper into a vision of student learning based on active investigation, dialogue, and reflection. They were the teachers who were willing to be the first to try out new practices and to encourage colleagues to do the same. They were the teachers who would act as

informal mentors to new teachers. The professional development for these Teacher Facilitators included learning to examine their own practice through use of classroom video, peer coaching, and eventually lesson study. In addition, through reading, presentations, and role-play they examined change models, such as CBAM, and played *The Change Game*. In interactive sessions they probed, practiced, and planned for their own roles in establishing positive norms of collaboration in their schools. Teacher Facilitators also played an essential advisory role to the project leadership as we continually reevaluated our strategies and plans. Their on-the-ground interpretation of the needs and disposition of their colleagues was indispensable.

4) Although not directly a professional development strategy, the hiring of new teachers has been and continues to be one of our most important supports for change. Our careful hiring practices reflect the unanimity of vision and purpose in our administrative team. Every candidate for a teaching position typically passes through a series of three interviews that include teachers, principals, curriculum directors, and the superintendent. Not every newly hired teacher has prior experience with programs such as *FOSS, Investigations,* or *CMP*. In fact, many are new to teaching. However, we only hire teachers who have particular predispositions. These include an inquiry-based approach to instruction, collegiality, dialogue and reflection, intellectually curiosity, and a passion for teaching students to be independent thinkers. This has helped fuel the engine of cultural transformation that is crucial to change.

Assumptions Meet Reality

We were guided by several ideas that simultaneously drove our forward progress and at times provided speed bumps and curves on the road.

First, since most teachers had received their "basic training" in the use of new curriculum materials, we wanted to create the conditions and provide the experiences and resources for them to be willing to move on to the "next steps" we had defined in our proposal. Second, we knew that not all teachers would be interested in or ready to pursue the deeper content knowledge and the sustained probing of student thinking that were at the heart of our goals. However, we assumed that by providing curricular and classroom-level support and then bringing teachers together across a variety of experience and dispositions, we would catalyze the desire to do so. We expected that this would progress in a "two-steps forward one step back" fashion, but eventually reach a sustainable *critical mass* of teachers. Third, we assumed that models, such as DMI, essentially designed for volunteers, could be adapted to work with a "command" audience of all teachers.

Not surprisingly, our premises and the strategies that were derived from them played out differently depending on the audience. Elementary teachers responded in distinctively different ways to workshops related to mathematics and science. Middle and elementary teachers responded with varying degrees of interest to adult content-based investigations. For example, when we began our *Pedagogical Content Knowledge Workshops* most teachers had several years of experience with *Investigations, CMP and FOSS.* However, many teachers remained skeptical and uncomfortable about a constructivist approach to teaching and learning in mathematics. Alternatively, no one argued that science would best be taught in approaches that were contrary to the inquiry-based approach chosen by the district. In fact, virtually all of our elementary and middle school science teachers were thrilled to finally have materials and a developmental series of lesson as the basis for their instruction. Discomfort with some shifts in content between grades as we implemented *FOSS* and other programs was only temporary.

Elementary Mathematics:

In our school-day workshops, we began to dig deeply into the mathematical content of elementary mathematics and the nuances of student thinking. Typically, presenters used activities derived from *Investigations* as the venue for adult content exploration, followed by examination of student work.

These sessions were a major departure from traditional expectations. They were decidedly not about taking home a new activity or set of materials, the classic "make and take" approach to professional development. Rather, they challenged participants' own knowledge and demanded a sustained analytical investment. Many teachers responded with real interest and enthusiasm. They were open to pushing beyond the limits of their own knowledge and excited about opening up a previously closed and shaded window into the understanding of their students. These teachers typically indicated that they had gained new mathematical insights and computational flexibility as a consequence of the sessions and curricular implementation.

Alternatively, there was a very small group that had strong philosophical objections to the constructivist approach to math instruction embodied in *Investigations*. A frequent complaint was, "We've already done this activity." This groups' disagreement did not permit them to see these "old" activities through a new lens. The fact that *Investigations* had been pioneered by colleagues and then implemented slowly and in stages did not matter. For a small, but vocal and resistant group, the sessions were a venue to air their anger at what they regarded as an imposed implementation. We had expected that many teachers, especially with respect to mathematics, would remain skeptical and uncomfortable about a constructivist approach to teaching and learning. However, we did not sufficiently anticipate the cultural dynamic this would create in a large workshop venue. We had not yet reached the "critical mass" of teachers necessary to establish a collaborative investigative culture.

A middle group, still struggling in the early stages of implementation with a different approach to mathematics, was caught in a cultural conundrum. Should they risk going public with a demonstrated interest in further exploration or sit quietly? Over time, this dynamic fluctuated, but eventually shifted so that sessions were more effective and positive.

Over time we were able to create a more effective workshops and a more positive response to these workshops. On the one hand time, persistence, retirements and hiring helped. On the other hand, we needed to change the structure and design of the workshops to be more responsive to faculty interest and experience. This required the project leaders to be intensely involved in co-planning sessions with outside consultants whose primary experience had been leading introductory trainings and in working with self-selected volunteers. Working at a more challenging level with a more diverse, non-voluntary group was relatively new for most of them. Making the adjustment to a different type of audience took time and careful planning. Whereas in the early years, we spoke to workshop leaders about the goals and topics, project leaders began to play a more direct role in the detailed planning of sessions, attempting to take into consideration the expressed concerns of participants. We collected evaluations after each session and then during the days that followed, spoke one-on-one with a wide variety of teachers. These conversations served two important roles. First, they gave us deeper insight into teachers' responses and reactions. Second, they delivered a powerful message that we were interested in what they thought. Over time, and with flexibility on the part of project leadership, the culture would change and become far more positive. However, it took longer than we projected.

One of the most positive outcomes of this approach was to change the entry point for the content-based sessions. We started with our grant-driven agenda and a predetermined set of content issues to explore. We did not abandon the topics, but we shifted the emphasis. Prior to one of the rounds of sessions, we sent out a survey to all teachers that included the message below:

Dear Teachers,

We are in the process of planning for the next round of Critical MASS workshops for the spring. We need your feedback to make them as effective as possible. Below are some of the areas that you asked us to address on your evaluation forms:

- *Assessment*
- *Working with Special Needs, ESL, and other struggling students*
- *Opportunities to share with colleagues*
- *Looking at your own students' work*
- *Unit specific training for folks who are new to Investigations, particular units, or a new grade*
- *Addressing what is expected by the end of the grade*
- *At grade 4 especially: supplementary suggestions for fitting in topics required by MCAS, but not covered by Investigations*

The most significant issues for the most number of teachers seem to be: How to help those students who continue to struggle with the mathematics expected at their grade level; and, how to use assessment results to help students. Please help us by answering the question below.
What are the mathematical concepts that seem to be most difficult for your students?
Please be as specific as possible. For example, if subtraction is an issue, please try to describe what aspect of subtraction is troublesome. Also, please indicate whether this is a persistent issue for the majority of students or a consistent subset of students.

Beginning with the student learning concerns of teachers, rather than adult content, made sessions more relevant to teachers. We explored much of the same material, but aimed it toward issues directly related to everyday practice. We went through many changes, continually shifting strategy and emphasis while not loosing sight of our primary purpose--shedding light on how students struggle with and develop mathematical reasoning and content understanding.

While, these sessions were evolving, the engagement of our math staff developer in classrooms with teachers was also growing and changing. Teacher receptivity to having the math staff developer in classrooms as an investigator of student thinking, a reflector of teacher practice, and a modeler of constructivist pedagogy slowly evolved from wariness to acceptance to invitation. Flexibility and sensitivity to individual teachers' openness has been the key to success. One of the most productive of these roles has been as an independent listener to student thinking. This has provided an entry point for making suggestions to address the issue that teachers care about most, helping students who struggle.

However, at times the structure and timing of lessons limited opportunities to listen to students. This emerged as a key pedagogical issue. It became clear that many teachers were spending relatively more time on "lesson launch" and as a result had less time for student investigation and, at times, little time for a reflective summary. The structure of lessons in the *Investigations* and *CMP* teacher guides is based on the idea that students' individual and social struggle with problems was the primary vehicle for learning. The teachers' role is to provide provocative questioning and guidance. However, teachers' commitment to what they thought was a great and insightful opening proved to be among the most resilient of traditional ideas about math instruction. Many teachers tried to provide as much up front clarity as possible in order to avoid confusion during the investigation. As a counterpoint, some teachers' practices resulted in too little intervention during investigatory periods. Others, in an honest effort to help students feel successful provided "enabling" support that did not challenge students to be independent problem solvers. Due to the persistence of the math staff developer and our work in lesson study, these practices have shifted toward a more nuanced understanding of the delicate role of a teacher in a constructivist classroom. Many teachers are now guided by two essential evaluative questions in planning their lessons: *Who is doing the talking? Who is doing the thinking*?

Middle School Mathematics

All of the middle school mathematics sessions were grounded in *CMP*. As with elementary mathematics, new content and topic sequence, as well as a radically different pedagogy emerged as challenging issues. However, two differences mediated these challenges. First, the workshops were smaller, (20 participants,

rather than 40). This meant that the influence of a few who were challenging the choice of *CMP* was easier to address. Second, all of the teachers were genuinely intrigued by investigation of math problems. Understanding math was a critical element in how they defined themselves as teachers. Therefore, they were more willing to persevere in their own inquiries. As a result, it was easier for student investigations to emerge as a powerful tool to support student understanding. Third, we were able to maintain the same two highly skilled workshop leaders for all sessions across four years, thus providing consistency.

Elementary and Middle School Science

Much of what has been said about teachers' professional development experience with math holds true for science. However, we did not face a philosophical challenge. No one advocated for a didactic approach to science instruction. Teachers were thrilled to have materials and detailed curriculum guidelines with which to teach science in an active, student-centered fashion. Alternatively, pushing on the limits of elementary teachers' content knowledge was more challenging. In the early years of the project, we tended to design adult investigations that were somewhat different from those that students did. We wanted to make clear the sessions were not about activities to bring back to the classroom, but about teachers content knowledge and understanding of student thinking. Some teachers welcomed the opportunities we offered in workshops for adult learning, while others found it somewhat intimidating. For many, the connection between their deeper content knowledge and classroom practice needed to be more explicit. This is best illustrated by the differential response of elementary and middle school teachers to new or unfamiliar content. As with mathematics, middle school science teachers were more intrigued by in-depth investigation. The content of middle school science is already at a deeper level than in elementary schools. Adult misconceptions were much closer to those held by students. As a result, the direct application to their classrooms of clarifying adult content confusions was clearer. Not surprisingly, we also discovered that the less experienced teachers were in their use of the new curriculum materials and the less confident they were in their own content knowledge, the less they were able to accept this approach.

As we did with mathematics, we shifted the entry point in order to make the elementary sessions more accessible to teachers. An example of this approach is reflected in a session on the *FOSS Solids and Liquids* module with second grade teachers.

Several features made this session different from previous sessions. The adult activities were rooted in student investigations, but were derived from modules in subsequent grades. Although these investigations served to probe adults' mental models, they were set in the context of learning about what was expected of students in later grades. This approach enabled us to dig deeper into teachers' conceptual models in a manner that met their needs. Next, we provided concrete information about the typical naïve conceptions or misunderstanding that student tend to have. As a result, the effort to push on teachers' own conceptions had utility in helping them to avoid promoting student misconceptions in later grades. We also provided an analytic framework for making sense of students' struggles with the content. This included deciding whether students' misunderstandings were rooted in social knowledge, requiring clarification of definition or naming; physical knowledge, requiring more or varied investigation; or logico-mathematical knowledge, requiring additional reflection and dialogue to help students make connections among their investigative experiences. We then connected this framework to classroom assessment. This approach was more successful because it more directly addressed teachers' self-defined need to gain strategies to address students' confusions. In earlier sessions teachers sometimes said, "This is interesting for me, but I'm not sure what to do with it when I get back." Providing teachers with concrete information about sources of student misunderstanding provided them with a "take-away" that was not an activity, but tools for making sense of student thinking.

Currently, our work in science now has three foci: 1) Identifying the components of key concepts and typical development of student thinking, 2) making more effective use of student assessment as a

diagnostic tool, and 3) promoting more student writing to help students hone the conceptual development and explanatory capability. These foci continually bring us back to our original premise of refining and enriching adult content knowledge.

Supportive Classroom Culture

While not a part of the Critical MASS project, the introduction of a classroom management and behavior system, *Responsive Classroom,* had a dramatic impact of the receptivity of students to open interchange of ideas required for successful implementation of our math and science curricula. *Responsive Classroom,* developed by the Northeast Foundation for Children, promotes a collegial classroom peer culture. In fact, we designed a summer institute called *Management for the Inquiry-based Classroom.* Teachers commented frequently, that a more positive and risk-free atmosphere makes it easier for students to offer math conjectures and solutions, science observations and tentative conclusions, and peer critique without fear. In addition, the classroom management strategies have improved the quality of student collaboration and sharing, while lesson the burdens of materials management. This has provided potential for teachers to focus more on student thinking and lesson on investigation mechanics.

The Shift

At the end of our fourth year, we made a dramatic shift in our approach to professional development. In order to better meet the needs of teachers and provide them a greater role in defining their professional growth needs, we move away from the model of pedagogical content knowledge workshops and created our own version of lesson study. As of this writing, we have completed a year of lesson study. It has been, by far, the most effective professional development we have organized. That said, we could not have done so at the beginning of the project. All of the work we had completed during the first four years created a cultural readiness.

We laid the foundation for this transition in the first two years of *Critical MASS* when we recruited a team of about eighteen teacher leaders. During that time we began to encourage them to informally visit and form peer-coaching relationships with one another. However, we did not have a great deal of success. This only occurred sporadically, because it was a major shift the existing culture of teaching and we did not provide a consistent structure to support it. We learned that we needed to move beyond the limits of individual initiative toward a broader approach.

Our math staff developer initiated the next step with an invitation to one teacher leader to participate in a "video-paper" project, *Seeing Math*. *Seeing Math* is an online course developed by the Concord Consortium that includes teachers creating their own video cases studies and then engages them in collegial discussions about teaching practice. This teacher taped lessons in her classroom, met with others to examine and dissect the lesson, wrote reflections on her teaching, and posed alternate instructional strategies. Bravely, she then shared her classroom video footage at a Teacher Facilitator Retreat. Using this video case study at the retreat enabled us to model a collegial dialogue with the entire group. This provided the opening we needed. It also provided these teachers with a practical experience of what such discussions might look like.

We anticipated that the major barriers to opening classroom doors were cultural. Therefore, a major component of the retreat included an extended session on "norms of collaboration." This provided practice with a set of practical strategies that promote successful peer group interactions. It addressed negotiating the potentially choppy waters of differing views and expectations, especially with long time colleagues. As a result, another teacher joined the *Seeing Math* project. Then, several others invited our math staff developer to videotape their teaching and participated collegial discussions. Even with these positive initial steps, our efforts at enlisting a broader participation met with limited success. Again, the cultural barriers loomed large. Their discomfort, self-doubt and thoughts of "what will my colleagues

say?" overcame perceived benefit. The prevailing culture was teaching as an individual, isolated activity. Collaboration occurred frequently, but at individual initiative and within clear boundaries of low risk-taking commentary. These discussions were not necessarily framed by overall theory or analysis of improvement needs. Resulting improvements were therefore sporadic.

At the same time, evaluation feedback on the pedagogical content knowledge workshops told us that the large workshop format had run its course. Teachers had learned a lot, but wanted something more directly related to everyday practice. They wanted opportunities for smaller more intimate discussions. Project leaders had become interested in the potential for lesson study as they hear about this at national conferences and read about in journals. We decided it was time to attempt it with the entire staff.

At the recommendation of the teacher leaders, we set the stage for lesson study by engaging the entire K-8 Hudson administration and faculty in a half-day release time workshop on "Norms of Collaboration." The power of this session and the leadership of the Teacher Facilitators made this a turning point in the project. We conducted several more sessions with teacher leaders including video of others engaged in lesson study and reports from practitioners about "do's and don't". As a result, they agreed to be the first "volunteers," setting an example for their colleagues. Several years of gentle encouragement to teacher leaders to be "public" about their willingness to try new practices and to take risks had finally paid off.

The basic framework for our lesson study engages all the teachers on a grade in one school. This resulted in groups of three to five teachers working together in a pre-lesson planning conference, then a lesson observation, and finally a follow-up discussion. First, a volunteer describes the lesson they will teacher that day, its goals, and any issues they would like to the group to pay particular attention to during the observation. The group then offers suggestions for refinement and adjustment. The volunteer teacher defines the role of the observers. Generally, most teachers have felt most comfortable asking the observer to play an active role listening to students thinking. Following the lesson, the volunteer leads a discussion, asking for feedback. These discussions have been free ranging, most often centering on strategies to deal with the more challenging learning issues and students. Below is the framing message for the process that we have shared with all teachers:

Lesson study is an effort to improve instruction and student achievement though collaborative lesson planning and examination of student thinking. The focus is on improving teaching (lessons) rather than on improving teachers. It always assumes positive intentions and an attitude of continuous learning for teachers.

The questions below guide the planning, observation, and reflection sessions:

- *What are the mathematics /science content goals of the lesson?*
- *What are the mathematics / scientific thinking goals of the lesson?*
- *What are some of the strengths, confusions, partial- or misconceptions that you anticipate?*
- *How will the launch of the lesson be structured to motivate interest, help students understand their task, and build on what they know?*
- *How will the period of student activity be structured to address the goals, build on prior knowledge, and address possible confusions?*
- *What strategies are planned for differentiation?*
- *What evidence will you be looking for while students are working?*
- *How will the lesson summary be structured to maximize student participation and encourage reflection?*

By the end our first year with lesson study, our entire K-8 faculty who are engaged in math or science instruction had participated in three or four sessions. Although teacher leaders stepped forward to be the

first to be observed, the vast majority of the faculty followed their lead. The depth and vibrancy of the sessions varied from group to group, each one reflecting the experience, ideas and personality of the participants. However, in all cases it fundamentally changed the nature of discussions about math and science content and learning. The focus of dialogue was now squarely on the relationships among content goals, instructional strategies and student understanding. The advent of these sessions represents a sea change in the culture of teaching that was catalyzed by teacher leadership. In addition, it was enabled by a shift in the locus of interest and dialogue to students and away from teachers to teaching. Finally, the willingness of other teachers to volunteer was made possible by demonstrating that the sessions were consistently a safe place for open discussion in a small group.

One aspect of Hudson's lesson study model makes it somewhat unique. The Elementary and Secondary Math and Science Directors participated in almost every lesson study session. Their involvement gave impetus and support for teacher leaders who volunteered to teach the first lessons. It has also provided modeling for rich discussion. Alternatively, it required us to move beyond some teachers seeing directors solely in an evaluative role. Ironically, it has made the times when we do observe in an evaluative role more effective.

However, lesson study has yet to become a normative sustainable practice. Teacher leaders have indicated consistently that making it so will require an institution-wide systemic shift in the culture of teaching and the work culture of schools and administration. We believe we have set those changes in motion.

Looking Back to the Future

Constant reflection among project leaders on our progress and the challenges we face, along with consultation with teachers, have made it possible for past experience to point the way to future possibility.

Initially, we felt the key to refining curriculum and instruction was to enrich content and pedagogical content knowledge in the context of collegial dialogue and reflection. Looking back, we are still confident those three components-content knowledge, pedagogical content knowledge, and collegial dialogue and reflection--are the tripod supporting improved student learning.

However, we underestimated the time it would take to move forward. We needed to work closely with workshop leaders to make adjustments to account for differences between volunteer and command audiences. We coined a phrase to describe this: "Never underestimate the resilience of the status quo." As the leader of the project, I often reminded others of a lesson learned from Geoffrey Moore's *Crossing the Chasm.* His basic premise is that the success of innovations depends on leaders recognizing that what motivates the first wave of pioneers is quite different from what motives others still willing to change. We needed to begin by demonstrating how new instructional approaches responded to teachers current concerns in order for them to fully embrace reform and all the new potential it holds for student teaching and learning. Finding the specific strategies to address this principle was a challenge. The importance of the shift from professional development approaches designed for volunteers to those that would better fit the needs and interests of an audience that was required to participate cannot be overstated.

Another difficult challenge was differentiating professional development to meet the needs of teachers at different stages of development. The size of our early sessions made this especially difficult. We continued to provide first level support for new teachers, leadership opportunities for the most willing, and a volunteer summer institute focused on both inquiry and math and science synergy. The dynamic of these volunteer events was highly energizing and positive, building collegiality and thereby providing support and sustenance to teacher participants, teacher leaders and project staff. The success of the voluntary aspects of our professional development, as well as working directly with teachers in the

classroom improved the effectiveness of general sessions over time. However, capitalizing on the diversity in these sessions remained elusive at times.

A key component of our work has been examining student work. This was a useful collaborative exercise throughout the project, but at times missed a key ingredient that might have made it more effective. We have come to recognize that examination of student work needed to be informed by developmental rubrics for each key concept in science and math units. This led to the development of a successful NSF funded Research on Learning in Education project *Formative Assessment in Science through Technology (FAST)* collaboration with the Lawrence Hall of Science. We are researching and creating "Developing Concept" hierarchies that describe the typical student developmental trajectory for each concept in a science module. These include both naïve conceptions and misconceptions. Our preliminary research indicates that the availability of these developing concepts helps teachers clarify their goals, anticipate student thinking, focus instruction, and develop curricular refinements to better meet students' learning needs. Teachers' engagement in identifying these levels has been worthwhile. However, making such developmental maps available to teachers based on the accumulated knowledge of the field is every bit as reasonable as providing developed curricula. Frequently, we identified levels of student understanding, however, we now think we need to provide more directly to teachers and to be more explicit about strategies to address confusions and misunderstanding. In short, a more diagnostic approach is needed.

Conclusion

We are at the cusp of a transformation. At the outset, we posited that increased teacher content and pedagogical knowledge in combination with the development of a collegial culture would be the essential components of improvement of math and science teaching and learning. Over the years, we have come to appreciate the extent to which these three elements are interwoven. They are all of one cloth, but the culture of the teaching profession and the classroom are the threads that bind the whole fabric together, give it strength and provide resilience. The more we support a systemic "critical friends" culture that models the best of the practice of scientific and mathematical inquiry, the more likely it will be that enriched adult knowledge will be translated into increased student appreciation for reasoning and rigor as a source of scientific and mathematical knowledge.

There is also an inherent tension between teachers' deep nurturing desire for all children to succeed and the need to let them struggle for a time. An arbiter of that tension is disposition of adults with respect to the role of authority in the development of knowledge and in decision-making. At times, the desire of adults for students to learn the basic facts and procedures looms far larger than our desire to have them learn to think and reason like scientists and mathematician. At times, our desire, as project leaders to have teachers adopt certain practices overwhelms the recognition that internalizing such practices takes time, patience, persistence and struggle. This self-defeating tendency derives from the profoundly resilience of the notion that we can impart knowledge to others, by telling, by authority. Wrestling with making sense of how students think as a guide for instruction is hard work and requires a high tolerance for ambiguity. Our success will depend on our collective willingness to engage in this work because our most important and lasting impact on students will be teaching them to use reason, logic and evidence in the context of positive social values in decision-making.