Abstract Title:
Defining the Aims of STEM Education in an Era of Hyperpluralism

MSP Project Name:
MSPGP (The Math Science Partnership of Greater Philadelphia)

Presenter:
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Strand 1

Summary:
The factor most responsible for the elusiveness in defining effective STEM teaching is the fundamental problem in reaching clarity and consensus as to what should be the aim of STEM education. We live in an era of "hyperpluralism" where a vast number and variety of contending groups and individuals involved in K-20 education, and the larger public and policy world, each stake their claim, or harbor their private definition, as revealed by their actual practice, as to the purpose of STEM education. Based on our nine years of operating a targeted MSP, we share the first results of a research supplement to provide a historical-based taxonomy of different aims as a way to negotiate consensus about the meaning of effective STEM teaching.

Section 1: Questions for dialogue at the MSP LNC

1. What process/procedures does your MSP utilize to reveal the various purposes that different people at various levels K-20 system ascribe to STEM education?
2. How congruent are a teacher's stated purpose and the methods/behaviors exhibited in their classrooms?
3. How does your MSP deal with cross purposes and incongruities?
4. What are the STEM educational aims of your professional development and/or your MSP program?

Section 2: Conceptual framework

We have developed a taxonomy of 16 different potential aims of education that are based on a historical analysis of major trends in education and profound changes in U.S. society over the past 400 years. Historical as many of these aims are, they, nonetheless, continue to remain alive to this day and vie for position and emphasis. Essentially, we have come to regard effective teaching in "STEM" as a loaded phrase whose answer depends first on the purposes of a schools' educational aim. For example, if one has as the purpose of education to equip the student with "useful knowledge" in a practical sense of everyday life, then the STEM curriculum and instruction will need to be designed with that aim in mind. For example, many high school math teachers will cite as one of their ultimate aims as having their students "be able to balance a checkbook." The definition then of effective STEM teaching becomes relative to that aim. On the other hand, if one has a vocation aim, then connections with engineering, information processing, allied health and other technical and research entities need to be incorporated into the curriculum. In this case, what may define effective STEM teaching is determined by how well students are prepared to enter post-secondary studies along these career pathways.

We chose Professional Learning Communities(PLCs) as the
vehicle to study the intentionality behind teachers' practice because you can't get at the "why" as to what teachers are teaching unless you sit down and have a conversation with them and probe their reasoning. So, for example, many high school math teachers when asked, "What is your highest outcome you want for your students when they leave 12th grade?" say "financial management," e.g., to be able to balance a checkbooks. But when then asked why they are teaching their students trigonometry, they shrug their shoulders. And their students do the same. The aimless leading the aimless.

Section 3: Explanatory framework

The keys to determining what is, in fact, effective teaching is the equality and nature of the assessment instruments and how well or not they are aligned with the aim of the curriculum. If, for example, a teacher states as his or her goal to "produce STEM thinkers," then what it means to be a STEM thinker needs to be unpacked and defined with sufficient specificity as to permit an external observer to be able to determine whether or not, and to what degree, a student has indeed become one. Whether that teacher has been effective in their STEM teaching, then will be gauged by the indicators and assessment modalities that are aligned to such a purpose.

The subject matter purpose is determined first by the *school's* aim, or, to use an architectural term, the school's parti that informs, constraints, and shapes subject area aims in the construction of specific curricula. In Part 1 of our forthcoming book, *The Hope of Education,* we trace out about 16 different aims of education over 400 years of American history that are rooted in profound changes that occurred leading to their emergence. We begin in 1620 with the Puritan aim of religious salvation for a predestined elect by equipping them to discern Satanic influences and end with the latest emergent educational aim in the 21st century of "sustainability" - globally, nationally and locally. I present selected schools or movements as embodying principally one these archetypical aims. The upshot is that all of these 16 different aims are still with us today in one form, variation or another and vie for attention. All have compelling reasons for their inclusion. And that is the challenge of hyper-pluralism today.

At the university level, the fields and sub-specialties of mathematics and the sciences are very diverse. In mathematics alone, for example, there are about ten different PhD areas: 1.Algebra and Number Theory 2. Real, Complex, Functional, and Harmonic Analysis; 3. Geometry and Topology; 4. Discrete Math/Combinatorics/ Logic/Computer Science; 5. Probability; 6. Statistics/Biostatistics; 7. Applied Mathematics; 8. Numerical Analysis, Approximations; 9. Linear, Nonlinear Optimization and Control; 10. Differential, Integral, and Difference Equations;

(based on the Fall 2009 Employment Status of 2008–2009 Doctoral Recipients by Field of Thesis, published American Mathematical Society
http://ams.org/profession/data/annual-survey/2009Survey-Second-Report-Supp-Table1.pdf

If you want a coherent program of study in elementary and high school, how these fields get played out at lower levels depends on what the overall purpose and thrust is of the school taken as a whole. So you start by defining a school's purpose then the subject matter follows, rather than with specific subject matter and then somehow try to justify why you are teaching this rather than that.

Section 4: Lessons learned

When we first wrote our MSP proposal in 2003, we did not grasp the extent to which hyper-pluralism in departments, schools and districts contributed to the lack of alignment of their purposes, policies and practice as related to science and mathematics. Engineering and technology was basically off the radar screen in K-12. Our MSP began, somewhat naively, by offering schools and districts a large menu of summer institutes and academic year professional development that was jointly created by teams of university faculty and teacher leaders. Only later did we realize we needed to first explore the often unconscious beliefs and culture norms that determined the direction of STEM education and the nature and methods of STEM teaching that mediated how teachers would actually implement what they learned in our PD sessions. Because of this realization , midway thorough out MSP we shifted toward the use of professional learning communities (PLCs) as a vehicle to explore the intentionality behind teacher practices and why or why not it was effective and the evidence to support it their judgments.

Abstract Title:
Inequality for All: Identifying and Addressing Curricular Policies Supporting Systemic Inequality in Mathematics

MSP Project Name: PROM/SE

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Summary:
The "effective teaching" concept informing the Promoting Rigorous Outcomes in Mathematics and Science Education (PROM/SE) MSP focused on what is taught together with a commitment to provide all students with a challenging and rigorous curriculum. Professional development helped teachers understand linkages between topics taught in their classrooms as well as linkages to those taught earlier and in subsequent years. The point has been to bring coherence to the curriculum both from a disciplinary viewpoint as well as from the experience of students as they move through all the grades of schooling. After more than five years of effort, PROM/SE has found some evidence that this approach has benefited students.

<u>Section 1: Questions for dialogue at the MSP LNC</u>

How might an emphasis on curriculum alter the current discussion around teachers and teaching?

How can this concept of effective teaching become part of the local education context?

What role can parents play in encouraging a focus on this type of effective teaching, i.e., a focus on coherent and challenging curricula?

<u>Section 2: Conceptual framework</u>

At the heart of the Promoting Rigorous Outcomes in Mathematics and Science Education (PROM/SE) MSP has been the focus on providing *all* students with a challenging and rigorous curriculum in these subjects. This focus came about from insights about the US mathematics and science curricula that emerged from the Third International Mathematics and Science Study (TIMSS). The US curriculum, compared to those in other countries and particularly in the highest-achieving countries, was found to be "a mile wide, inch deep." Thus from the outset, the PROM/SE conception of "effective teaching in STEM" was grounded in the "what" that is to be taught both in terms of the *intended* curriculum, e.g., standards and curriculum guides, as well as the curriculum *implemented* in classrooms by teachers. The efforts and practices of teachers may be very compelling but the substance of their efforts must be connected to and reflect a larger vision of what is important for students to know from a perspective that is larger than any single classroom. In addition to a focus on rigorous and challenging curricula, the foundation for "effective teaching" in PROM/SE has included the idea that *all* students can learn and benefit from such a curriculum; that *all* students should be afforded the very best opportunities to learn the very best curriculum.

In this way the PROM/SE concept of "effective teaching" is not about doing a better job of identifying and tracking the best and brightest into the most challenging opportunities but about bringing all students to a desired level of competence and literacy with respect to mathematics and science. In doing so, the concept of coherence in the curriculum within as well as across the grades of schooling is particularly salient. From the perspective of students, as important as what occurs within any one year of schooling may be, how these years knit together into a coherent understanding of the subject matter is even more critical. This coherent model of "effect teaching" requires teachers to view themselves and to operate as active members of a coherent community of educators fostering coherent understanding in students.

Section 3: Explanatory framework

Questions of educational equity have been at the center of discussions of educational policy since at least the Coleman Report. In fact the very title of the most recent renewal of the Elementary and Secondary Education Act (ESEA), "No Child Left Behind," was dubbed with the intention of highlighting the importance of making sure that *all* students, would have access to a quality education. Racial and ethnic minorities and students from low-income households continue to trail their peers in educational achievement, whether measured by performance on standardized tests, high school graduation, or college attendance and completion

Across the nearly 60 PROM/SE districts, we examined the relationship between inequalities in student opportunities to learn (OTL) mathematics and science and school districts' underprivileged status. Results were revealing: if there is a strong relationship between race and SES on the one hand and OTL on the other, then it would provide support for the idea that racial achievement gaps are in part a product of differences in OTL. If there was no relationship, then we would have evidence that there are in fact two different sorts of gaps: one based on race/SES, the other on OTL, which would require two distinct policy approaches to address such gaps.

We found that the effect of underprivileged status on OTL varies considerably over time. In elementary school there are relatively few differences across the 4 SES groups in what topics were covered. Most of the variation was within rather than across district types. In middle school, both the most and least advantaged districts covered more topics, while the two middle categories covered fewer topics. In 7th grade the relationship between SES/race and OTL was pronounced, as the more affluent a district became the more advanced mathematics topics were covered. However, this coverage was not made up in later grades, suggesting that students from lower-income and predominantly minority districts were receiving less instruction in those topics. There was also a tendency for more basic math to disappear from the curricula of affluent districts, while poorer students were still being taught these subjects. In terms of time of coverage per topic, lower-income districts spent substantially more time on basic mathematics, which meant that they were much less likely to receive grounding in transitional mathematics, with serious long-term consequences as these differences in OTL accumulate across grades.

In short, there are large differences in learning opportunities operationalized as time spent teaching specific topics. Such differences are related to both the socioeconomic climate of the district and its racial/ethnic composition but such factors do not explain all the variation across all districts. There are important differences across districts that affect students in all districts; not just those in poorer neighborhoods or those in high-minority areas. Being exposed to an underachieving curriculum that does not reflect coherence, focus, or rigor disadvantages many students. Thus the PROM/SE focus on bringing a rigorous and challenging curriculum to all students. While this may not be a sufficient condition for effective teaching it is certainly a necessary prerequisite.

Section 4: **Lessons learned**

The achievement gaps between districts can only be explained in part by the differences in socioeconomic and racial/ethnic composition. However, a very large proportion of these differences are related to the large gaps in the curriculum in place within districts; differences in the definition of the curriculum that is the basis of any effective teaching. Bringing a focus on the coherence of the curriculum – reducing the variation in topic emphasis within each grade and carefully selecting which topics to focus on at each grade level – has demonstrated benefits for student learning.

Abstract Title:
Defining Effective STEM Teaching Within a Middle-School/Post-Secondary Collaboration Through a Cycle of Logic Model Development

MSP Project Name: SF Bay Integrated Middle School Science Project

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Summary:
This proposal focuses on the first year of implementation of an NSF MSP grant. The process of developing and using logic models helped our project define effective STEM teaching and learning, and refine and evaluate project goals, outcomes and activities. These goals, outcomes and activities have continued to evolve and be clarified over the first year of the project using a logic-modeling process involving key partners, project staff, researchers and our evaluator. The logic model process helps us to reveal and negotiate core assumptions; align project components; network across groups; share learnings about effective STEM teaching; increase coherence across all partners and build capacities of all partners for inquiry-based teaching and learning.

Section 1: Questions for dialogue at the MSP LNC

1. How to facilitate and document core project assumptions of all partners?
2. How can logic models be used collaboratively across the partnership to refine:
   a. A collective definition of effective STEM teaching and learning
   b. Project goals, activities and outcomes
   c. Theories of action and theories of instruction
   d. Evidence of progress
3. How can the development of annual logic models focus, guide and structure collaboration that supports effective STEM teaching and learning?

Section 2: Conceptual framework

Developing a collective understanding of a conceptual framework is particularly challenging given the number of districts and other partners in our grant. To develop a common vision across the partnership, we would like to share how we used logic modeling to:

1. Build consensus about teacher quality, professional development, teacher preparation,

coaching
2. Identify challenges and resources within and across partners
3. Raise critical questions about inquiry and project strategies
4. Facilitate diversity yet negotiate core assumptions about a project's theories of action and instruction, operational definitions and indicators of short and long term progress.

Our project is basing our definition of "effective teaching in STEM" on the National Science Education Standards definitions of inquiry-based science teaching. We are using the Inquiry rubric from the National Science Education Standards for assessing teachers' use of student-centered approaches to teaching science in the middle school. The rubric defines five essential elements that include:

1. Learner engages in scientifically oriented questions.
2. Learner gives priority to evidence in responding to questions.
3. Learner formulates explanations from evidence
4. Learner connects explanations to scientific knowledge
5. Learner communicates and justifies explanations.

Many years of research have demonstrated the positive effects of inquiry-science teaching and learning (Cohen & Spillane, 1993; Lee, Hart, Cuevas, & Enders, 2004; Lott, 1983; National Research Council [NRC], 1996; Shymansky, Kyle, & Alport, 1983; Von Secker & Lissitz, 1999 Wu & Hsieh, 2006).

The National Science Education Standards defines inquiry as:

"Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries. Although the Standards emphasize inquiry, this should not be interpreted as recommending a single approach to science teaching. Teachers should use different strategies to develop the knowledge, understandings, and abilities described in the content standards. Conducting hands-on science activities does not guarantee inquiry, nor is reading about science incompatible with inquiry." (NSES, 1999, p 23)

The National Science Education Standards (NRC, 1996, p. 32) describe how inquiry-based teachers "focus and support inquiries while interacting with students," "orchestrate discourse among students about scientific ideas," "challenge students to accept and share responsibility for their own learning," "recognize and respond to student diversity and encourage all students to participate fully in science learning," and "encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.”

Project Design related to defining effective STEM teaching and learning.

This five-year, $12 million project funded by the National Science Foundation, has been developing and studying a comprehensive professional development model designed to transform science teaching and learning in predominantly low-income middle schools serving underrepresented minority students and English learners. The project design is grounded in an extensive body of research and evidence-based best practices in science instruction, professional development, and systemic reform.

Project goals are to: (1) Increase the quality, quantity, and diversity of middle school science teachers by providing professional development and coaching support so that teachers improve science content knowledge, pedagogy, inquiry, and leadership (2) Create online PD anchored in exemplary inquiry-based investigative science instructional cases (lesson plan, assessment, and resources) aligned with the Foundational Level General Science Credential and state and national science standards, and (3) Develop partnership infrastructure to support systemic change through a coherent focus on building science instructional leadership capacity.
Just beginning our second year, we are taking an ecological approach with a special focus on six schools. Our perspective is that if we can understand how multiple program implementation efforts embedded in complex ecologies of diverse partners operates, then this knowledge will help advance future programs seeking to operate in real world ecologies. (Collay et. al., AERA 12)

<u>Section 3: Explanatory framework</u>

The IMSS project team identified goals and outcomes for the project when writing our proposal. These goals and outcomes have evolved and been clarified over the first year of the project using logic modeling process involving key stakeholders, project staff, researchers and our evaluator. We developed a logic models to illustrate the interrelationships among the program’s goals, activities, and structures. In the logic modeling process, agreement and consensus are reached on what is valued as outcome and process. As suggested by Weiss (1998), our team chose to engage in a process of goal construction from the values and goals of our stakeholders including CSU scientists, coaches, core partners and researchers.

The logic model can serve as the basis for program evaluation, research and project management plans, involving stakeholders in logic modeling process so that buy-in and “ownership” occurs, which is central to the success of the subsequent evaluation and research efforts and use of results (Torres, Hopson & Casey, 2008). In using the logic modeling process our IMSS project team engaged in the collaborative development and discussion of logic models for various elements of the project. These logic models started with a 5-year logic model generated during the initial proposal preparation phase over two years ago. Once funded, different project subgroups then collaboratively developed separate annual logic models in the areas of research, professional development, coaching and for each core partner organization.

The evaluator, director, and project researchers collaborated to work with all subgroups during (and after) the logic modeling process. We focused on building capacity of partners as well as some subgroups that cut across partners to use logic modeling as a strategy to identify core assumptions, focus priorities each year, and serve as a management tool to self-monitor progress.

This process has helped each group identify clearer goals, theories of action and actionable outcomes. It has also helped align the various project components and partners. We are hoping to see a shift from procedural understanding to conceptual understanding as subgroups meet regularly to reflect on progress and outcomes of their work. Individual logic models serve as a tool for inquiry into the various project components and groups. The process of modeling and the product of negotiated models serve multiple purposes: a project management tool, evaluation tool and reflective tool for each of our groups and the project as a whole. The logic model process has helped us to reveal and negotiate core assumptions; network across groups; share learning's about effective STEM teaching; increase coherence across all partners, build capacities for inquiry-based teaching and learning, examine distribution of leadership and build towards systemic instructional change in all partner organizations.

We are currently interested in three directions regarding logic modeling:

1. what is needed to facilitate logic modeling across the partners?
2. How does logic modeling capacity evolve over time across various partners and subgroups?
3. How does logic modeling contribute to sustainable capacity building of various stakeholders regarding project planning, implementation and evaluation use?

Logic model facilitation has been enabled in the second year of the grant by combining two strategies: 1) an active listening and non-judgmental probing process (Palmer, 1998) and 2) using four questions to ensure that what we were all co-constructing was culturally responsive (Wlodkowski & Ginsberg, 1995). This inquiry process became more intentionally evaluative by collaboratively identifying questions to focus lesson study school work and project-wide work, prioritizing questions with evidence, collecting and analyzing both student achievement data and data related to teacher practice and school or classroom context, and then using this data to make decisions about teaching and improving practice

Working in collaboration project management, evaluators and researchers applied grounded research design (Glaser, 1992; Charmaz, 2006; Bryant & Charmaz, 2007) to document the emergence of core project assumptions. Constant comparison of various logic models generated across the partnership was conducted. The result was seven categories identified, which were interconnected to each other. Progressive accessing and reading of related literature was part of the data collection process. Indicators of each category were identified over the past two years. The categories were 1) Continuous collective improvement; 2) Culturally responsive practice; 3) Building capacity for Communities of Practice; 4) Network Learning; 5) Distributed Leadership; 6) Authentic Partnership; 7) Data enhanced systemic instructional change.

Section 4: Lessons learned

The lessons learned from our first year using logic modeling may have value to MSP Start and targeted/institute partnerships early in their implementation. It may also appeal to evaluators, who may be interested in learning how to use logic modeling in their work. Specifically, a series of learnings are emerging including:

1. The process of logic modeling may be more important in the short term than the products given the rapid development and shifts that a partnership is likely to go through in the first year of implementation.
2. Though “collaboration” was envisioned in the original grant proposal, the structure and processes that evolved and were associated with “collaborative” activities within the project were not fully conceptualized in the grant’s first year. Collaborative structures are now emerging, which enable resource leveraging and more efficient capacity building across the project as the evolving core principles demanded.
3. The original program outcomes, research questions and evaluation plan have remained but the questions and methods for both evaluation, research and program design have been refined with the increasing emergence of transformative principles over time.
4. Another result has been the development of an ecological framework leveraging the seven categories, which reflects the partnership’s evolution of core assumptions and strategies regarding instruction and learning. This process has been ecological in the sense that it has increasingly leveraged the values and expertise of its diverse partner members with external factors such as: state and national standards, research-based best practices, outside process and content consultants as well as external evaluation.
5. The significance of collaboration and networking of teams within and across partners became clearer to the project management over time. This collaboration and networking required critical reflection about unexamined assumptions made in the first year. Initially, the project leadership assumed that offering professional development to team members would be sufficient for transferring data and building capacity
6. Since summer 2011, partners have been increasing their capacity to develop and use logic models for the various project goals. The project leaders and evaluator co-designed a logic model template to be used by all subgroups. Included in this template was the explication of theories of action and theories of instruction. We plan on logic model construction and modification being an annual process at the end of each summer followed by a sharing out of lessons learned during June of the following year.

Abstract Title:
Using Energy as a Cross-Cutting Concept to Teach More Effectively

MSP Project Name:
Boston Energy in Science Teaching (BEST)-BSP Phase II

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Strand 1

Summary:
The Boston Energy in Science Teaching (BEST) project defines effective teaching as facilitating opportunities for learners to explore concepts and connections across science disciplines. Our project's strategy is to use the cross-cutting concept of energy to facilitate these opportunities for teachers by adapting our phase I professional development (PD) strategies to be cross-disciplinary instead of disciplinary specific. We believe that using concept-based PD will lead to more effective and efficient instruction compared to discipline-based PD. To test this we will be comparing data of grade 3-8 teachers who participated in our discipline-based PD through the BSP, teachers who participated in both, and teachers who have only participated in BEST.

<u>Section 1: Questions for dialogue at the MSP LNC</u>
What preparation do our teachers need to competently teach with the big ideas in mind?

How do teachers effectively make the connections for students and help students make connections for themselves?

How do we teach with the big ideas in mind when state assessments tend to focus on specific, lower-order content questions?

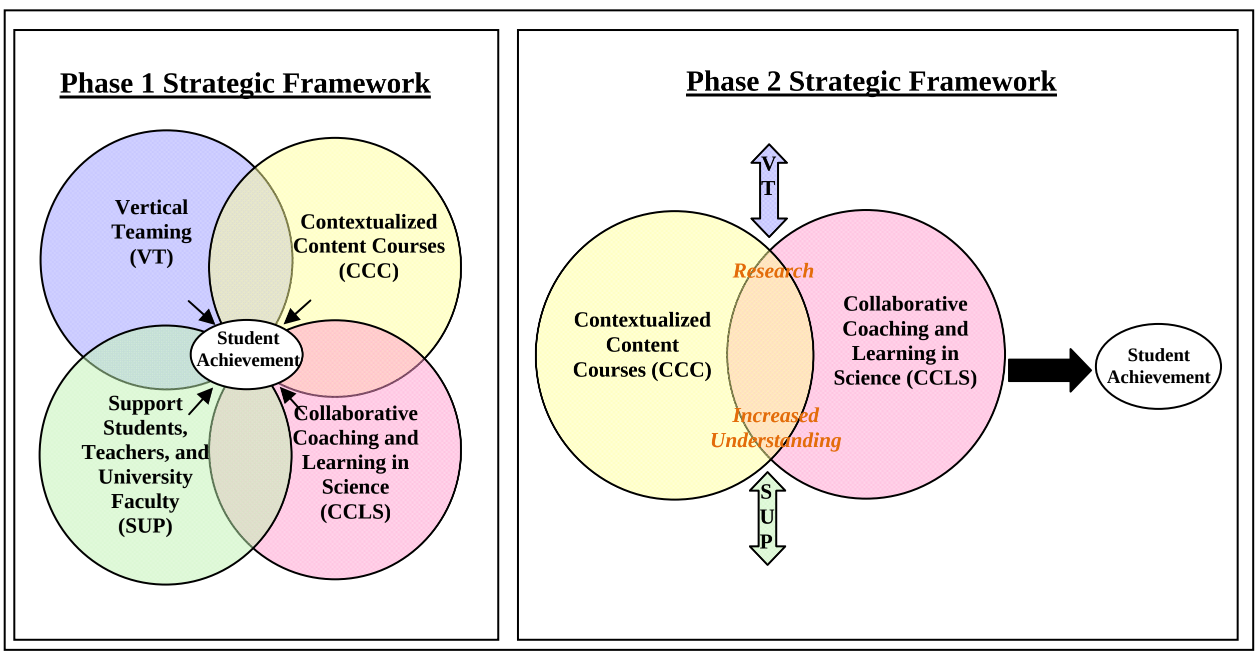
What evidence from our project's experience with energy would be needed to convince others that effective teaching is anchored in using the big ideas as a theme in instruction?

<u>Section 2: Conceptual framework</u>
Boston Energy in Science Teaching, the Boston Science Partnership's Phase II project, is anchored in using energy as a cross-cutting concept. As a project, BEST defines effective teaching in science as facilitating opportunities for learners to explore concepts and connections

across science disciplines. Our project's strategy is to use the cross-cutting concept of energy to facilitate these opportunities. To achieve our goal of effective teaching through the use of energy, we have adapted our Phase I BSP professional development strategies (Vertical Teaming, Contextualized Content Courses, and Collaborative Coaching and Learning in Science) from being discipline-based to concept-based [energy]. Vertical Teaming has helped to identify where energy is taught in the BPS curriculum—which will be used to inform out other strategies—and our Energy I Contextualized Content Course has increased teacher conceptual knowledge about energy. The design of our Energy II course is a blend of Vertical Teaming (VT), Collaborative Coaching and Learning in Science (CCLS), and a Contextualized Content Course (CCC). In Energy II, teachers go deeper into energy content across the major science disciplines and look at how these concepts are translated into a K-12 classroom through the sharing of video lessons. The teachers then use the CCLS model to discuss where energy is in the lesson, how it can connect to other lessons, and how it can be leveraged for future learning. Our project will be comparing participants who participated in BSP PD (discipline based), BEST PD (concept based), and both BSP and BEST PD to see if one type of PD has a greater impact on teaching and student achievement than another. Implicit in our program and research design are our assumptions about effective teaching. These assumptions include:

- Professional development can lead to an increase in teacher effectiveness and this change in effectiveness can impact student achievement.
- It is beneficial to learners to think about science as a whole and the connections within it, as opposed to thinking and learning about science only in disciplinary silos.
- BEST does not think that energy is the only theme that is useful for effective teaching that results in connecting science across disciplines.

Figure 1. Metamorphosis of original Boston Science Partnership's strategic framework to the strategic framework of the Boston Energy in Science Teaching project.



Section 3: Explanatory framework

BEST is primed to have three types of findings at the conclusion of the grant: identification of energy connections across K-12 curriculum, evaluation of how grades 3-8 teachers perceive of their own changes in instruction, and research findings that will lead to recommendations of the impact of different types of PD on grades 3-8 teacher instruction and student achievement.

Identification of Connections: Before starting this project, we knew that energy was pervasive through all science disciplines. However, we did not know how difficult it would be to organize the connections and how to know which connections are the best ones to highlight in the classroom since a teacher cannot and should not be connecting everything through energy. Through this project, we hope to be able to clearly articulate the most important energy connections to make in K-12 science and where they are in the (BPS) curriculum. These clearly articulated connections should have the impact on increasing teacher effectiveness because they will know—as opposed to guess—which connections should be highlighted, when to highlight them, and where in a unit to make the connection. As a teacher begins to get better at making the connections for students and showing students how and why two content ideas are connected, then the student should start to be able to make those connections for themselves in energy and potentially in other areas.

Evaluation Findings: Our evaluators—with regard to effective teaching—are primarily interested in determining the impact that participation in BEST PD has on teachers, including self-reported changes in instruction, confidence, and their understanding of how energy connects across the curriculum as well as the ability to transfer knowledge from one discipline to another. Furthermore, while we will limit this proposal to mostly grade 3-8 impacts, the evaluation also is collecting self-reported data about changes in instruction at the university level, in our Energy I and Energy II co-instructors and participants in our energy Professional Learning Communities at the university level. Among other indicators, the evaluation is collecting data about (self-reported) changes in faculty instruction, including increases in references to energy concepts and to courses in other science departments.

Research Findings: In this project, we are researching the effectiveness of disciplinary based *vs.* concept based professional development on student achievement. We are attempting to do this by comparing teachers who have participated in only BEST related PD, only BSP related PD, and both. Our research tools include interviews, teacher assessments, student assessments, state-assessment data, and classroom observations for participants in all three groups. We anticipate being able to state what type of impact concept-based professional development has on instruction and that these impact findings are supported by student data on an energy assessment, changes on energy question responses on MCAS, observed changes in instruction, teacher data on energy assessments, and interview responses. From these data, we will be in a better position to know if teachers are able to teacher better—according to our definition of effective teaching—when thinking about the big ideas of science (specifically energy), how professional development can best support these changes in teacher effectiveness, and if student data confirms these changes. Changes we will be looking for will be increases in teacher and student content knowledge on assessments, more connections to other content areas through the thread of energy observed in lessons, and more articulation of the importance of energy connections and big ideas during interviews.

Section 4: Lessons learned

Throughout the first year of this project, we have learned many lessons around effective teaching. These learnings around effective teaching can be categorized into three major areas: learning progressions, assessments, and content knowledge.

Learning Progressions: Prior to starting this project, we were aware that an energy learning progression did not exist. However, we did not realize how crucial a learning progression would be to the work that we are doing. Furthermore, although energy is pervasive throughout the science and the K-12 curriculum, it is not at the forefront of what we do. The number of connections a teacher could make in a year would be overwhelming. Therefore, we are in a position of having to not only test our hypothesis that concept based PD is more efficient and effective but also build the content for the PD from scratch

Assessments: The transference of teacher knowledge to student knowledge is the black box in education research. The only way we will be able to say what the impact of concept-based PD is on teacher effectiveness is through constant assessment of various methods, including teacher assessments, student assessments, and observations. We knew of an energy assessment that was developed through another NSF project and chose to use that with our teachers. However, that assessment did not match the objectives and content of our professional developments so we were unable to detect change. We have decided to create a modified assessment that incorporates questions from the original energy assessment, AAAS questions, and project-developed ones. We are still open to other suggestions on measuring changes in effective teaching, but we think we now have a good plan of increasing our recruitment strategy to recruit three different cohorts of research participants and use the modified assessments that we developed, teacher interviews, surveys, and observations to get at any changes that may occur.

Content Knowledge: We have learned that it is incredibly hard for any one IHE faculty member—who has made their career on being an expert in a specific area—to have enough content knowledge across the science disciplines to effectively teach our energy course. However, this is exactly what we ask our elementary and middle school teachers to do. Additionally, we are not sure how immediate the impact on teachers may be. In our BSP project, faculty members needed 3 years to see effective changes in their own instruction. Unfortunately, we do not have that time in this project so we need tools that provide either an indication of change or some concrete examples of change occurring or not occurring. Through our assessments, we should see an increase in content knowledge gained by teachers outside of their “home” discipline; and this, according to our core assumption that an increase in teacher content knowledge leads to an increase in teacher effectiveness will have a positive impact in the classroom.

Abstract Title:
Understanding Barriers to Change and Innovation in STEM Teaching and Learning: Silos and District-wide Teacher Learning Networks

MSP Project Name: EnLiST

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Strand 3

Summary:
Effective precollege STEM teaching provides students with meaningfully integrated horizontal (within-grade level) and vertical (across-grade levels) innovative experiences across scientific disciplines. This approach requires a holistic transformation of STEM learning across the curriculum and school experiences. This study adopted a social network perspective on learning to understand how innovation is 'taken up' by teachers across school buildings or districts, and characterized the nature of extant science teacher learning networks within a whole school district. Results show that science teachers' learning networks were mostly siloed within buildings with hardly any cross-grade, cross-level, and cross-building relations. Additionally, teacher networks related to science teaching and learning were less elaborate when compared to other networks, such as those related to learning about classroom management.

Section 1: Questions for dialogue at the MSP LNC
How can we think about “effective teaching in STEM” beyond the instructional practices of individual teachers? How would “effective teaching in STEM” across levels, across a school building, and across a district look like?

How can “effective STEM teaching” be made both a horizontal and vertical endeavor that links teachers and integrates their efforts across subject matter areas within and across grades, and/or within and across school level? How would an effective “whole school or district” STEM teaching look like? What sorts of teacher learning networks support such an approach?

Section 2: Conceptual framework
Effective precollege STEM teaching provides students with meaningfully integrated horizontal (within-grade level) and vertical (across-grade levels) innovative experiences across scientific disciplines. This approach requires a holistic transformation of STEM learning across the curriculum and school experiences. However, effecting change and innovation in K-12 science teaching and learning has been, and continues to be, a major challenge. Despite continued and

substantial reform efforts, the greater majority of K-12 science classrooms are still typified by traditional instructional approaches rather than the much advocated and desired inquiry and reform-oriented teaching and learning modalities (Crawford, 2007; Lynch, 2001; Smith & Southerland, 2007). To be sure, change in K-12 classrooms and schools depends to a significant extent on external "inputs" including—among many other things, conceptual and empirical developments in curricula and instructional approaches, as well as effective and sustained teacher professional development (Wei, Darling-Hammond, Andree, Richardson, & Orphanos, 2009). However, it has long been recognized that factors "internal" to schools, particularly those related to teachers are as, if not more, important than external inputs in effecting change and innovation (Budd Rowe & Dehart Hurd, 1966) and is especially characteristic in the teaching of STEM fields. Discourse and research on 'resistance' to reform and innovation among teachers in general (e.g., Muncey & McQuillan, 1996) and STEM teachers in particular has mostly focused on the dissonance between teachers' knowledge, attitudes, beliefs, and practices and those entailed or advocated by reform efforts (e.g., Craig, 2001; Davis, 2002; Fetters, Czerniak, Fish, & Shawberry, 2002; Haney, Czerniak, & Lumpe, 1998), and on the tensions and misalignments between school culture and structures and teacher perspectives on, and actions related to, reform and innovation (e.g., Davis, 2002; Thomas, 1995).

In this context, the study that we will present and discuss features an alternative focus. Coming from a social network perspective on learning, the study focuses on how innovation is 'taken up' by a school building or district, whereby the internalization and enactment of innovative ideas, discourses, and practices is thought of as collective 'learning' across the school building or district. From a networks perspective, this much desired learning is made possible through the exchange of ideas, information, and resources among members of school and district networks, and the mobilization of resources and resulting social capital to address the needs of innovation and sustain its implementation through developing successful and effective communities of learning and practice (Authors, in press, 2010, 2011; Daley, 2010; Rogers, 1995). This study, an outgrowth of initial research reported last year at the LNC for the EnLiST (Entrepreneurial Leadership in STEM Teaching and learning) project, supports the projects' goal to nurture entrepreneurial teacher leaders who recognize and act on opportunities to innovate in their classrooms, and disseminate innovations in their school buildings and districts toward reform-oriented STEM teaching modalities. Given the Project's focus on change and transfer of innovation, and social networks perspective on learning, a crucial first step in our research was to understand the existing teacher learning networks within our partner school districts. There hardly is any empirical research in science education that examined whole schools or school districts social learning networks systematically despite the attunement of science teacher educators and researchers to the value of teacher relationships and collaboration, and their importance to the realization of the potential of professional development in effecting change (e.g., Ball, Jones, Pomeranz, & Symington, 1995; Briscoe & Peters, 1997). This state of affairs, nonetheless, is not surprising because, even though networks have been considered as powerful platforms for learning in research outside the context of schools, applying this perspective to research in schools has been taken up only recently (Authors, in press; Daly, 2010).

Thus, the purpose of this study was to characterize the nature of extant science teacher social learning networks within whole school districts. The aim was to understand the current state of information exchange around science and science teaching, which allow gauging whether and how school and district learning networks support exchange and collaboration between knowledgeable and expert colleagues needed to initiate and sustain innovation. The study helps establish a baseline for science teacher learning networks in the Project's partner school districts, which will allow tracking the ways in which Project teachers contribute to building, strengthen, and/or build on existing networks by means of annual data collection efforts throughout the life of the Project.

<u>Section 3: Explanatory framework</u>

Research on the way information circulates a network shows not only how resources are embedded in the network, but also how they transfer from one person or part of the network to another (Authors, 2010; Lin, 2001). Learning is, of course, more than just receipt of information. It also entails taking up and incorporating information into personal understandings and practice, and further dissemination. Research on networks show that relationships make the difference between just hearing information and being convinced of the worth of adopting a novel practice. Thus, in the context of learning, close attention is paid to how, and between whom information, is exchanged.

A social network is evident from the connections among *actors* who are *tied* to each other by the maintenance of one or more social *relations*. This often is visually displayed as a graph with actors as nodes connected by lines (relations), which create an overall network pattern. Members of organizations connected through relations of information sharing, employer-employee relations, and group membership are such networks. Teachers connected via common interest in science, meetings at administrative functions, and membership in a school system are other such networks. Network studies address the triad of actors, relations, and networks. Individuals are asked about interactions with others: Who did you hear from about this innovation? Who do you go to for support? With whom do you discuss important matters? Data gathered from members of the same network provide input for a *whole network* view (Authors, 2001, 2006). Both circulation and uptake of information (i.e., learning) depend on the nature of the interpersonal tie between people. The literature makes a distinction between 'strong tie' relationships maintained with friends, co-workers, and family, and 'weak tie' connections with less known others. Studies established that awareness of innovations (Rogers, 1995), access to new information, and readiness to recognize new practices (Cohen & Levinthal, 1990), depend on a diverse communication structure and engagement with people and ideas outside the local network, which might include weak-tie relations (Maroulis & Gomez, 2008). By contrast, persuasion to adopt an innovation (Rogers, 1995) and provision of social support is more likely to be accomplished through strong-tie connections between individuals who know each other well and are more like each other within the local network (Marsden & Campbell, 1984).

A social network perspective opens up a number of ways to examine learning. We can think of learning as the content of a single relation that connects people (e.g., "I learn from a colleague"), or the characterization of the tie, based on multiple, contextually determined relations. A learning tie, thus, may emerge with a colleague because he or she provides suggestions about teaching, but also for career advice and social support. At a network level, learning can be a characterization of the outcome of relations (e.g., as a group becomes a learning community); or as a network outcome of relations (e.g., as the resulting social capital of the community exceeds the sum of what is held by individuals). The different takes on learning help understand how social networks support learning. At a practical level, what we discover about learning relations can serve as input for design of more effective information dissemination and learning systems within a network. For example, network relations may show that face-to-face meetings are the most effective way for gaining understanding of a new knowledge domain, but a web site is more effective for supporting common knowledge; or that dissemination of innovation entails creating opportunities to meaningfully connect key actors across the network who otherwise are not likely to establish relationships (see Authors, in press).

Toward this end, all instructional staff in the participant school districts (Core Project school partners) were asked to respond to an online survey. The survey listed the full names of ‘all’ staff members in a respondent’s school district. To help respondents manage navigating the survey, district organizational units (schools, instructional support centers, district office(s), etc.) appeared as active links, which expanded into lists of the full names and positions (e.g., Jane Doe, math teacher) of all personnel in those units. Respondents could expand or collapse lists at will. They were asked to consider interactions with people in the district over the last year. For each listed name, respondents were asked to indicate whether they *learn from this person* about: (a) classroom management, (b) science teaching and learning, (c) teaching and learning in other content areas (not science), and (d) mentoring or career advice. They were asked to put a check mark beside the name of a person for each of the four categories that apply. If they did not know the person or did not have interactions around these kinds of learning, respondents were instructed to leave the item blank. These four categories of ‘learning’ were tapped to get comparative data about learning networks related to science teaching as compared to that in the other domains.

In addition to ascertaining the existence of relations, we also were interested in their strength and frequency. Thus, in the last column on the survey, for each person with a check mark by their name, respondents were asked to consider all aspects of their interactions with this person, and then indicate their overall level of interaction with him/her on a five-point scale, from “few interactions of limited scope” to “frequent interaction of substantial scope.” Finally, respondents were invited to add names of people inside and outside the school district who are important to their learning. These included teachers or administrators whose names did not appear in the list, friends or family, people they studied with, or people in other kinds of work. They were asked to provide as full a name as possible and, if known, the individual’s title and/or area of expertise. If full names were not known, respondents were asked to provide the role in which they know the individual (s)they added (e.g., former colleague, university instructor, retired teacher, family friend).

In the presentation we will share our detailed findings, which are best represented through images and graphs. Briefly, what was particularly interesting about the findings is that learning networks replicated the structural organization of school districts. Without knowing anything about a particular district, the district structure (e.g., a central office, two elementary, a middle, and a high school) was clearly recognizable in the layout of the learning network images. The structural entities within a district were replicated in the learning networks along definite silos (with more inter-unit connections) that are linked (with fewer intra-unit connections) through, and to, formal channels (albeit not always ‘learning’ channels) embodied in school and central office leadership. The character of the learning network characteristic of a whole district was replicated in all categories of learning (e.g., science learning, classroom management, mentoring). While not totally surprising, this finding helps explain the well known difficulties that hamper systemic change across districts, whereby major agents of change (i.e., teachers) are not connected within learning communities. Communication around innovation, instead, is channeled through individuals (bottle-necks!) who might or might not have the expertise needed to facilitate the dissemination, persuasion, modeling, and support needed to effect change.

Additionally, while science teacher learning networks were generally similar in layout to the overall and other categories of learning networks, they were decidedly thinner. Thus, not only were science teacher learning networks siloed within buildings, they also were relatively less dense within buildings compared to building networks associated, for example, with classroom management. Extant science teacher networks in the districts would not support the communities of learning and practice needed to bring about systemic change or innovation. The EnLiST efforts to link science teachers across grade and school levels around 'vertical' initiatives seem to be supported (and likely to be effective) given these findings.

Network densities were highest in junior high: The more integrated approach to teaching and learning in middle school was translated into a denser learning network. In comparison, elementary and high school networks were consistent with the compartmentalized classroom and disciplinary-based instruction in the latter two levels respectively. Again, learning networks reveal the sort of difficulties facing systemic change and innovation across districts.

Section 4: Lessons learned

There surely is a need to reconsider the unit of analysis when we think about "effective teaching in STEM." To effect the sorts of change, innovation, and transformation needed to reinvent teaching in STEM to meet the needs and challenges we all face, we need a systems-thinking approach to conceptualize the "effective." Going about the usual business of training teachers so they can be better instructors within the confines of their classrooms simply will not cut it. As the old adage goes, "It takes whole village to raise a child"; it takes a whole school to enact effective teaching in STEM. The present results indicate that silos that typify teacher learning networks (or lack thereof) need to be understood and taken into account when approaching the problem of transforming STEM teaching and learning for all children.

The EnLiST project efforts have been directed toward nurturing teacher leaders who bridge subject matter areas, as well as grade and school levels for the purpose of transforming the *overall experiences* of school students with the things we call STEM. The present results has taught us that we had underestimated the extent of what we thought our partnership was up against in creating transformative STEM learning experiences. We seem to be on the right track in terms of building learning networks across our partner school districts. The present study will help us pinpoint bottlenecks, as well as natural connectors (people who bridge silos meaningfully) who can help strengthen teacher learning networks and deepen the impact of the EnLiST Teacher Fellows in their buildings and across their districts.

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Abstract Title:
Exploring the Effectiveness and Utilization of Teacher Leader Support and Resources Through Social Network Analysis

MSP Project Name:
LEADERS: Leadership for Educators: Academy for Driving Economic Revitalization in Science

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Strand 2

Summary:
Student engagement is the hallmark of effective STEM teaching. It is student-centered and includes iterative cycles of authentic scientific investigation centered on real-world issues through collaboration between students, teachers, and members of the community in a collaboration of inquiry. As such, teachers must be aware of and take advantage of the wealth of community resources that can translate relevant issues facing students to the classroom. Social network analysis (SNA) can compare teacher leader interactions with the partnership's support to determine strengths and weaknesses. Our findings revealed that support use was linked to school district dynamics, teacher preferences, and teacher awareness of supports. Results allowed the partnership to improve support offerings thereby improving STEM teaching. This presentation includes SNA graphs and interpretations.

Section 1: Questions for dialogue at the MSP LNC

- How can MSPs determine whether their teacher leader preparation and support model is effective?
- What is the relationship between teacher leader use of the MSP supports and resources and effective STEM teaching?
- What types of supports do teacher leaders use most frequently? The least frequently?
- How can identification of teacher leader supports linked with effective STEM teaching outcomes inform the MSP for program improvement?

Section 2: Conceptual framework

Our project asserts that effective STEM, and specifically science, teaching is inquiry-based and generative. In other words, it is student-centered and includes iterative cycles of authentic scientific investigation centered on real-world issues through collaboration between students, teachers, and members of the community (university faculty, scientists, and science related industry) in a collaboration of inquiry. Project Based Science (PBS) is the foundation of our conceptual framework. PBS pedagogy is built around five features that are used to design activities that: 1) engage students in investigating a real life question or problem that drives activities and organizes concepts and principles; 2) result in students developing a series of artifacts, or products, that address the question or problem; 3) enable students to engage in investigations; 4) involve students, teachers, and members of society in a community of inquiry as they collaborate about the problem; and 5) promote students use of cognitive tools (Krajcik, Blumenfeld, Marx, & Soloway, 1994). By involving students with members of society, students learn about important scientific career possibilities. To engage students in experiential learning opportunities that help them connect themselves to the world—whether neighborhood or global issues—the teacher must have a solid mastery of both content and pedagogy.

Even when teachers are well versed in inquiry-based instructional theory and strategies, implementation is limited. Roehring (2004) identified five constraints that inhibit the implementation of inquiry based instruction: a lack of understanding of the nature of science, limited content knowledge, limited pedagogical content knowledge, personal teaching beliefs, and concerns about student and classroom management. This is especially prevalent with new teachers. A teacher leader who can develop PBS lessons that have been tested and provide students with relevant applications of scientific theory could provide the guidance and support necessary to ensure both new and veteran science teachers implement inquiry-based instruction.

To enact change, teacher leaders need a support system, or network, including all stakeholders (teachers, school administration, higher education, community, parents) that both encourages and expects reform. The range of a support network has been found to be positively correlated with career success and satisfaction (Hetty van Emmerik, 2004) but all members of the network must share a common vision of the reform measures to be implemented.

Quality preparation and a full complement of relevant supports are essential to the success of teacher leaders as they first improve their own science teaching and subsequently provide guidance and training to their mentees. LEADERS recognizes that it is unrealistic to expect teacher leaders to accomplish the daunting task of transforming science education alone and therefore has included a network coach, school district principals and administrators, university science educators and scientists, informal science, and industry partners in the preparation and support team.

Section 3: Explanatory framework

Early findings suggest that there are some roadblocks to the implementation of PBS and therefore effective science teaching. Social network analysis (SNA) applied to resource use allowed us to compare teacher leader partnership resource/supports use with measures of effective science teaching (Science Teacher Self Efficacy Instrument, Science Teacher Ideological Preference Scale, and the Horizon Inside the Classroom Observation Instrument). Our findings indicated that teacher leaders seldom used resources that would best help them in overcoming these roadblocks. For example, teacher leaders make little use of scientists and science graduate students outside of the summer institute. Measures of effective teaching indicate that the teacher leaders are weak in the area of providing a true PBS lesson—one that is modeled after scientific investigation. The scientists and science graduate students are best poised to assist the teacher leaders in the design of a series of inquiry-based lessons that focus on a driving question. The relationship between support use and effective teaching may not be causal; however, increasing teacher leader use of resources that best support their weaknesses is expected to improve science teaching.

The SNA also provided the opportunity to compare resource/support use between the two partner school districts. While some differences were due to district demographics (like the use of a district science support person), other differences and similarities illustrated trends. The project network coach, an unique position in this project designed to assist teacher leaders as they provide professional development to their district teachers, was utilized and valued by all teacher leaders thereby reinforcing the decision to include this component of the project. On the other hand, an online virtual meeting space designed to facilitate communication and networking among teacher leaders (between and within school districts) was used only during the Summer Institute when it was required. An initial assumption might be that the teacher leaders did not interact during the academic year. Quite the contrary, however, as was revealed in a follow up focus group interview. The teacher leaders used alternative means by which to communicate—email, texting, telephone, and Facebook.

Section 4: Lessons learned

Often there is the assumption that if quality resources and supports are provided, the teacher leaders will make use of them. Before this assumption can be tested, however, we must validate that our perception of a useful, quality resource is indeed shared by the teacher leaders. SNA allowed us to see graphic interpretations of teacher leader resource/support use. As a result, a clear picture of the teacher leader value for or awareness of resources was provided. Some supports that had been assumed to be essential to the success of the teacher leaders as effective STEM teachers were, from the teacher leader perspective, redundant or of little value. The identification of those resources and supports that entertained little use allowed us to improve the manner in which they were offered and evaluate whether they truly can contribute to effective teaching and, if so, clarify how they might support effective teaching.

In addition, we learned we must ensure that the teacher leaders are aware not only of the resources and support system in place but also understand how these resources might apply to their role as teacher leaders (i.e., their usefulness). Finally, we learned that there really is no “aha!” moment but rather that the teacher leaders evolve through the process of developing an understanding for the implementation of project based science gradually. As such, their use of resources and supports grows in concurrence with that understanding. Through frequent communication with the teacher leaders, we can gain a clear understanding of where they are in the process and therefore better provide the type of support that will be used to develop more effective teaching practice.

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Abstract Title:
A Test-of-Concept Study of a Learning Theory-based Model of Professional Development

MSP Project Name: AIM: K-8 Science

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Strand 2

Summary:
Assessing the Impact of the MSPs: K-8 Science (AIM) is working with MSPs to study the impact of different professional development strategies on teacher content knowledge and student learning. As part of this broader study, AIM is conducting a "test-of-concept" study for a learning theory-based model of professional development. We hypothesize that professional development consistent with this model will increase teacher understanding of the targeted content and provide teachers with the tools and support needed to teach science effectively (in a manner aligned with the vision of science instruction described in the framework for the Next Generation Science Standards). This session will share initial findings of the impact of this model on teacher knowledge, classroom practices, and student learning.

Section 1: **Questions for dialogue at the MSP LNC**

- What do teachers need to know and be able to do to be effective science teachers?
- How can professional development be designed to help bridge the gap between where teachers are now and where we want them to be?
- What role do instructional materials play in preparing and supporting teachers to teach effectively?

Section 2: **Conceptual framework**

Assessing the Impact of the MSPs: K–8 Science (AIM) defines effective teaching in STEM as that which promotes student development of a deep, conceptual understanding of (1) important science ideas, and (2) the evidence-based nature of science as a way of knowing (which is an integral component of the framework for the Next Generation Science Standards). AIM has hypothesized that both of these goals can be accomplished using a learning theory-based model of instruction (Banilower, Cohen, Pasley, & Weiss, 2010) that includes surfacing learners' initial thinking, engaging them with evidentiary phenomena (i.e., phenomena that provide evidence for the targeted science idea), having them draw and critique claims based upon evidence, and connecting what they experienced to the targeted idea, their initial thinking, and other science ideas (i.e., providing opportunities for sense making).

Professional development (PD) is one of the major channels for bringing about changes in teaching, though the science education field has not reached a consensus with respect to the characteristics of PD that best facilitate effective teaching. The MSP program has focused on the importance of teacher content knowledge, as there is evidence that professional development with a focus on teachers' content knowledge is more likely to influence changes in classroom practice and support student achievement, compared to programs that focus on more generic topics (Cohen and Hill, 2000; Kennedy, 1999). However, both Cohen and Hill (2000) and Kennedy (1999) found that an emphasis not just on content knowledge, but also on student learning of the content, were related to measured student learning. A series of studies conducted on the effectiveness of mathematics and science education professional development supported with Eisenhower program funds (Desimone, Porter, Garet, Yoon, & Birman, 2002; Garet et al., 1999; Garet, Porter, Desimone, Birman, & Yoon, 2001) found that teachers who participated in activities that emphasized content knowledge, active learning, and coherence with other improvement programs were more likely to report enhanced knowledge and skills, and changes in their teaching practice than teachers who did not participate in such programs. The study also found that these emphases were more common in professional development that had a longer time span, had a greater number of contact hours, and encouraged collective participation of teachers within a school, grade level, or course. It is important to note, however, that this study relied on teacher self-report in determining gains, rather than more objective measures.

The AIM project seeks to shed additional light on the role of PD in increasing teacher content knowledge and teaching effectiveness. To this end, AIM is working with both NSF- and state-funded MSPs. We have developed pairs of teacher and student content assessments that measure conceptual understanding of selected science topics. In Component One of AIM, partner projects are providing information about their PD approaches and administering content assessments to teachers before and after their PD. In Component Two, teachers are providing information about their classroom practices and are administering pre- and post-unit content assessments to their students.

However, data from our first year of work indicated that there was little variation in the professional development approaches being used by our partner MSPs. To examine what the relative benefits of different PD approaches are on teacher knowledge, classroom practice, and student learning, AIM developed and delivered a learning theory-aligned PD program. The goal of this piece of our work (which we call Component Three) is to provide a "test of concept" to determine the impacts of this model, which we believe is both replicable and scalable, relative to other PD approaches.

The PD program we developed for upper-elementary teachers focuses on ideas within force and motion. It includes a week-long summer institute with three main foci. The first is deepening teachers' conceptual understanding of the targeted ideas using a learning theory-based approach. The PD also emphasizes the connections among the ideas, in particular how the smaller ideas lead to the "big ideas," through a guided building of a conceptual map (which we call a "content framework") for the topic. Second, the PD engages teachers with the content in a way that they can easily take back and apply to the classroom through the use of learning experiences that are low-tech, low-cost, and that reliably provide evidence for the targeted ideas. Third, the PD specifically aims to develop teacher understanding of why the PD and classroom materials were developed the way they were—that learning theory implies that learners' initial ideas need to be surfaced, they need to engage with phenomena that provide evidence for scientific ideas, they need opportunities to draw and critique conclusions from this evidence, and then they need to consider how their thinking had changed and apply their new understanding to other contexts. Thus, the PD includes periodic opportunities to step back from the science investigations to examine the relationships among target ideas and analyze the pedagogical approaches utilized in the workshop.

In addition, we developed an implementation guide for the workshop activities that is meant to be "educative" (Davis and Krajcik, 2005) and provide on-going support for teachers. This guide includes a summary of the learning theory-based instructional model on which the materials are based, and specific implementation support for each activity. For example, the surround for each activity lists the ideas targeted, naïve conceptions about those ideas students are likely to have, suggestions for focusing students on the relevant aspects of the evidentiary phenomena, suggestions for what to do if students aren't "getting it," as well as practical guidance for the mechanics of the activity.

As part of our test-of-concept study, we measured teacher disciplinary content knowledge before and after the PD. During this school year, our participants are administering a corresponding student assessment in their classes at the beginning and again at the end of their units on force and motion. Teachers are also completing questionnaires that ask them to characterize their initial preparation for teaching force and motion, provide contextual information about their teaching situation, and describe their instruction during the unit. Finally, substantial portions of the teachers' force and motion instruction are being observed. These measures will allow us to examine the relationships among the PD, teacher content knowledge, classroom instruction, and gains in student content knowledge.

AIM Timeline

	Year One	**Year Two**	**Year Three**	**Year Four**†
Component One	X	X	X	X
Component Two		X	X	X
Component Three			X	X
Analysis and Dissemination				X

† Anticipated no-cost extension year.

Section 3: Explanatory framework

The PD program we developed is based upon a hypothetical model of what teachers need to know and be able to do for effective teaching to happen. To a large extent, our model is based upon Shulman's (1987) idea of pedagogical content knowledge (PCK) that has been expanded upon by others (cf. Magnusson, Krajcik, & Borko, 1999). However, using a learning theory lens, we focus our model on the following domains of teacher knowledge:

1. Knowledge of how to sequence ideas for students: This domain refers to knowledge of which ideas are pre-requisites for later ideas and how to progress from less to more

complex ideas. This way of thinking about content has been referred to as a "psychological organization," which contrasts with the "logical organization" characteristic of a scientist's thinking. A logical organization begins with the most general (and often most powerful) concept in a discipline—e.g., energy in physics—and organizes all other concepts under it. A student, however, is not likely to be able to access the content presented in this way, thus a psychological organization is needed.
2. Areas of student difficulty: To help students understand content, teachers need to know what ideas students are likely to bring with them and where they are likely to struggle. This domain includes knowledge of which ideas are difficult for students to learn and why, as well as preconceptions/naïve ideas students often have.
3. Knowledge of content-specific strategies that can build students' conceptual understanding: Such strategies may take on a number of forms, including:
    a. Activities (e.g., investigations, discrepant events) that confront students with phenomena which provide evidence for the targeted idea.
    b. Representations of content (e.g., models, examples, analogies) that are particularly effective in revealing the subtle aspects of a content area. These representations are especially important in understanding phenomena that are not easily or directly observable such as the random motion of particles in a liquid or gas. Examples and analogies have the potential to link new content to experiences with which students are already familiar.
    c. Questions that, if asked at the right point in a sequence of instruction, can move students' thinking forward.
4. Knowledge of methods of assessing science learning: This domain includes knowledge of activities/representations/hypothetical scenarios, etc. that can be used to diagnose the thinking of students. Teachers need to know how to discern what ideas students have about a content area, both prior to and during a unit of instruction. Knowledge of questions or activities that are likely to elicit student thinking is particularly important.

Of course, effective teaching also depends on the extent to which all these types of knowledge are brought to bear in classroom instruction with a particular set of students in a particular context. Factors outside of the teacher knowledge domain, including curriculum and assessment mandates, the quality of instructional materials, and time restrictions can impact the application of teacher knowledge, and thus affect the quality of instruction.

However, we think that it is unlikely that teachers will have, or be able to learn, all of this PCK for all of the topics they teach, especially teachers who are asked to cover a wide variety of topics (which is quite common in elementary schools). What we do think is a scalable approach, and is inherent in our study, is to provide teachers with instructional materials that use a learning theory-based instructional model, use a psychological organization of the content, and incorporate activities, representations, and questions for diagnosing and moving forward student thinking. With instructional materials such as these, PD can focus on helping teachers understand the content, the instructional model, and the key features of the instructional materials.

Our study is testing this idea. Specifically, we are addressing the following research questions:
1. What impact does this PD model have on teacher disciplinary content knowledge? How

does the impact of our model compare to other PD models?
2. To what extent are teachers able to incorporate a learning theory-based instructional model in the classroom when provided with PD and instructional materials aligned with that model? What factors affect the implementation of this instructional model?
3. What impact does this approach to PD have on student learning? How does variation in implementation affect student learning?

If the results of this study show promise for this approach, we will use the data we gather to refine, and disseminate more broadly, the PD and instructional materials.

Section 4: Lessons learned

Although we are in the early stages of data collection in teachers' classrooms, a few themes appear to be emerging from the preliminary data. One is that even with a full week of learning-theory aligned PD on a single content area that was centered on learning-theory aligned instructional materials, teachers need ongoing support for and feedback on implementing what they learned during the PD in their own classrooms. In part, we think that this finding is due to teachers struggling with the pedagogical approach inherent in the instructional materials.

Second, even high-quality instructional materials need to provide educative supports to teachers. A single learning opportunity, regardless of the quality, is often not sufficient for deep learning to occur. Asking teachers to be able to implement what for many of them is a new pedagogical approach, months after experiencing it, in a content area that many still feel that their knowledge of is tentative, is not a formula for success. We have attempted to address some of these needs through an implementation guide for the unit.

Third, the instructional materials that teachers had prior to this experience are influencing their implementation of the AIM materials. In particular, our teachers appear reticent to question their school/district-provided instructional materials, even when those materials contain content errors (including ones that foster misconceptions). Adding a piece to the PD that helps teachers examine instructional materials with a critical lens may be helpful.

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Abstract Title:
Noyce Master Teacher Developed K-5 Science Curriculum and Professional Development

MSP Project Name: NCOSP

Presenters:
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Steve Gammon, Western Washington University

Authors:
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Steve Gammon, Western Washington University

Strand 2

Summary:
Six elementary and two middle school teachers were supported by the North Cascades and Olympic Science Partnership and their school district to research and assemble a coherent K-5 science curriculum. They are also supported to design and deliver professional development and instructional support for all of their peers in the district's fourteen elementary schools to promote effective science teaching as the new curriculum is implemented. As a result, in the first year the percent of fifth and second grade classrooms where science is consistently being taught increased from 18% to 68% and the school district has committed to continued funding for curriculum implementation and professional development. The support materials developed by the group are now available and being accessed and used by other districts including NCOSP partner districts, and the Noyce Master Teachers are providing advice and training to schools outside of their district.

Section 1: Questions for dialogue at the MSP LNC

What preparation did the teachers receive?
What support was provided by the MSP project and the school district?
What is the evaluation plan?
Is the impact on student achievement being measured?
How is university faculty involved?
What resources were provided by the MSP and the school district?

Section 2: Conceptual framework

Our innovative ideas synthesize three research areas into a coherent picture of **Effective Science Instruction** in the classroom. We bring together the cognitive science foundation described in the NRC report *How People Learn: Brain, Mind, Experience, and School* (NRC 2000), the research-based instructional strategies of Formative Assessment Process/Assessment for Learning (see for example William, 2011), and the research on the impact of professional teacher collaboration, including the critical role of building leadership (see for example Garmston and Wellman 1999, City, Elmore, Fiarman, and Teitel, 2009) and www.edtrust.org). An effective science lesson is a learning cycle that engages the student not only in the content, but also in the pedagogy, making leaning strategies transparent to increase student's self-efficacy. Students work individually, in small groups, or with the whole class when appropriate. At each stage, when appropriate, there are opportunities for structured teacher-, self-, or peer-assessment to generate information necessary for providing useful feedback to guide students. There is also the tacit assumption that adequate instructional materials are available. The lesson contains the following steps. It:

1. Begins with sharing important learning targets with students to make sure that each student understands the goal, how it will be assessed, and the criteria for success fully demonstrating achievement,
2. Draws out student's initial ideas about the learning target to make them visible to both the student and teacher,
3. Engages students in sufficient activities to gather evidence relevant to exploring the concepts in the learning target. These activities can be classical inquiries, observations of phenomena, exploration of text, technology-based simulations or demonstrations, or a lecture if that is appropriate,
4. Engages students in analyzing, thinking about, and reflecting on the evidence, initial ideas, and learning target and communicating their thinking to their peers and teacher,
5. Requires students to generate artifacts that demonstrate their evidence, analysis, and thinking. This can be a lab report, concept sketch, presentation, paper, solved problem etc. Assessment of the learning reflected in these artifacts informs the next cycle of steps 3-5 and the timing of when to continue on to step 6,
6. Brings the class together for a final sense making session to engage students in reflecting and communicating their new understandings,
7. Concludes with an assessment that gives the students the opportunity to demonstrate their learning. This assessment may be used for grading purposes or may be used formatively.

In our work, we add the additional expectation that teachers will continuously work to increase the effectiveness of their instruction through professional collaboration with their peers around student work, supported by their building and district leaders.

The project worked under the constraints of assembling a K-5 curriculum from existing published materials that had the potential of helping each student successfully learn science at least at the level of the Washington Science Standards. Candidate materials were identified through a careful evaluation process based on the AAAS Project 2061 curriculum evaluation procedure which the teachers had learned as part of their Masters in Science Education curriculum. The materials were then piloted in classrooms of the Master Teachers. The pilot experiences were used to develop a "map" of each material that makes the learning targets explicit for each lesson, a set of "Teacher Tips" for each lesson with suggestions for effective instruction, and a one-day professional development plan for helping grade-level teachers use the materials in their classrooms. In addition, each teacher has the opportunity for half-day of support from one of the master teachers on a specific aspect of implementation of personal interest. Incorporating science note booking, improving questioning strategies, helping students acquire and use metacognitive strategies, classroom observation and feedback, opportunity to observe a lesson in a Master Teachers classroom, and deepening content knowledge are among the supports offered.

Section 3: Explanatory framework

Evaluation data from teachers participating in the professional development indicate that this unique approach to curriculum implementation is both well-received and effective. Participants describe the professional development as the best they have ever received. It is remarkable to observe these PD sessions wholly designed and facilitated by district peers who are recognized and respected as experts in elementary science. In spite of the fact that attendance at the workshops was not required--and in a few schools discouraged by school principals--100% of the teachers enthusiastically participated. Surveys of teachers showed that science instruction in classrooms increased after the PD. In the first year after PD was done for second and fifth grade teachers the percent of classrooms where science was taught increased from 18% to 68%.

The district office has also recognized the value of the Master Teachers work by their commitment to purchase and implement the recommended curriculum materials at each grade. The district has also provided the funding to provide substitute teachers for all of the teacher participants at the professional development workshops.

Recent changes in the state science assessments make it difficult to measure changes in student achievement, but we should have a stable test for the next three years that will allow us to draw some conclusions about the impact of the new curriculum and its implementation.

Section 4: Lessons learned

1. The district and building leaders have a profound impact on the instruction offered to children every day and year. Current federal law and state and local interpretations of requirements has resulted in a hostile environment for teaching science, especially in the elementary grades. The development of a critical number of Master Teachers who can demonstrate the positive impact of effective science teaching on students reading and mathematics achievement and are strong advocates for teaching science can influence a subset of, but not all, principals and district leaders.
2. Well trained and supported peers can positively impact the teaching staff in a building beyond the impact of externally provided PD providers. When the training is done, these teachers are still in the district available to serve as resources to individual or groups of teachers. They are able to deliver targeted, rather than generic support.
3. A robust partnership between teachers in school districts and the science education faculty in the university, built on mutual respect, can sustain continued improvement of science instruction at all levels.

Abstract Title:
Localizing Teacher Leadership Expertise in Appalachia

MSP Project Name: Appalachian MSP

Presenters:
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Authors:
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Michael N. Howard, Independent Consultant/Evaluator

Strand 2

Summary:
The Appalachian Mathematics and Science Partnership received NSF supplemental funding for the AMSP Master Teacher Project. Eighteen experienced grade 6-12 mathematics and science teachers received a three-year program of mentored professional development and support designed to develop Master Teachers in mathematics and science who demonstrate effective teaching in their own classrooms and serve as leaders in the rural Appalachian region. Findings to-date indicate: most participants have shifted their thinking about instruction, moving from a focus on teaching to a focus on learning; they still vary in their conception of teacher leadership and their views of themselves as leaders; and the teachers have developed a strong professional network, valuing and using each other as sources of information, ideas, and support.

Section 1: Questions for dialogue at the MSP LNC
To promote dialogue at the LNC, the following discussion questions are pertinent to this session:
What differences are necessary in professional development designed for STEM teachers who are already considered to be (or who see themselves as) accomplished and effective?
How did participants' perceptions of "effective teaching" and "teacher leadership" change during the project? In what ways did changes in one area affect the other?
What changes result from shifting teachers' focus from improving "instruction" to improving "learning"?
How did the use of expert resources and the interactions through the professional network contribute to the observed changes?

Section 2: Conceptual framework
The Master Teacher Project's working definition of effective teaching in STEM encompasses the following capacities and actions, grouped broadly under three dimensions:

Planning and preparation for instruction: Units of study designed to surface and address student conceptions; organize learning experiences along a learning progression; develop and reinforce processes; and link targeted content to "big ideas" in the discipline.

Implementing instruction: Classroom environment and interactions that foster exploration and investigation; promote evidence-based thinking, argument and rationale; monitor student status and adjust activities accordingly; and foster a culture that respects intellectual rigor and collaborative creation of knowledge.

Creating a supportive context for effective instruction: Curriculum aligned with state standards and articulated across grade levels/courses; access to quality curricular materials and instructional resources; grading policies aligned with standards and desired outcomes; active administrator support for the vision of STEM instruction; collegial support for ongoing teacher learning and improvement.

The Master Teacher project, as a supplement to the larger Appalachian MSP project, could not address the complete spectrum of components encompassing the vision of effective STEM instruction. Instead, it focused on key elements that provided leverage points, both within the AMSP and in the larger context of state STEM education reform initiatives – classroom formative and summative assessment; instructional unit design; standards-based grading; instructional design and implementation to address diverse learning needs; and building a positive classroom culture for learning.

Design of the project included the following major components to prepare and support participating teachers for their expected role (LNC Strand 2):
Identification of a cadre of AMSP-participating teachers with interest and potential to develop as a local STEM teacher leader.

Monthly participant meetings for collaborative professional study of focal topics, as well as network development activities.

Interaction with national resource persons and projects engaged in STEM instructional improvement.

Collaborative work with an IHE faculty member and regional resource teachers.

Ongoing technology-based interactions among participants.

Culminating project to demonstrate professional growth and instructional improvement.
This project was designed to develop Master Teachers in mathematics and science who could demonstrate effective teaching in their own classrooms, as well as serve as leaders in the rural region served by the AMSP.

<u>Section 3: Explanatory framework</u>
Evaluation of the Master Teacher project examines questions regarding outcomes on two levels:

1) Classroom practice of the Master Teachers

    To what extent have participants changed their perceptions about and knowledge of effective teaching components addressed by the project?

To what extent have participants changed their perceptions about and commitment to the project’s vision of effective STEM teaching?

To what extent have participants implemented changes in their regular classroom practice as envisioned by the project?

2) Leadership influence on local STEM instruction and STEM programs

To what extent have participants changed their perceptions about and commitment to leadership for local mathematics/science programs?

To what extent have participants enhanced their knowledge and skills to engage in leadership roles?

To what extent have participants effectively influenced STEM instruction beyond their own classrooms?

To what extent have participants effectively influenced the STEM programs at the school and/or district levels?

Because of the small number of participants in the project (18), the evaluation takes a descriptive/qualitative approach with limited quantitative analyses as appropriate. Evidence is gathered through regular completion of perceptual inventories, classroom observations, reflective prompts, activity/implementation logs, and interviews/focus groups.

Evidence is still being gathered for the summative evaluation. To date, the following findings have been notable:

Most participants have shown notable shifts in their thinking about instruction, moving from a focus on teaching to a focus on learning.

Different participants have tended to focus on different aspects of the effective teaching components addressed through the project; they are still working on putting things together in an integrated fashion.

Participants are documenting changes in student outcomes in their classrooms, which they attribute to changes in their instruction stimulated by the project.
Participants are beginning to demonstrate more “program-level” thinking (thinking beyond their own classrooms).

Participants still vary considerably in their conception of teacher leadership and their views of themselves as leaders.

The role of the network is growing – participants continue to value their access to state and national resources and experts, but are increasingly valuing and using each other as sources of information, ideas, and support.

The nature and level of support from participants' administrators vary considerably, impacting participants' classroom changes as well as their opportunities for local leadership.

The data gathered thus far have informed the project's work in a variety of ways. Project leaders have shifted the emphasis on some topics to address participant interests and struggles, as well as to capitalize on opportunities to embed project activities in the broader state STEM reform efforts. As the participant network has matured, the project is featuring it more prominently as a means for professional learning and support. The project is actively seeking and promoting professional opportunities at the state and national levels for individual participants who demonstrate appropriate leadership interest and readiness.

<u>Section 4: Lessons learned</u>

Lessons learned through the Master Teacher project to-date include:
Shifts in teachers' beliefs and perceptions and shifts in their practice tend to follow a recursive process – not a sequential one – in which it is important to experience both "believing is seeing" and "seeing is believing."

Being recognized as an accomplished teacher does not necessarily indicate that a teacher is reflective about their beliefs, knowledge, and practices (or wants to be). The maturing of the network can be a significant contributor to enhanced reflection as some participants model it and reinforce its value to the others.

Significant shifts in perceptions and practice require time – after three years the Master Teacher project is beginning to see real changes. Moreover, the "growth curve" for most participants is not linear; it starts more slowly than you think it should, but then accelerates.
Maintaining administrator attention, awareness and active support is a continual challenge, exacerbated by shifting local and state priorities as well as changes in administration over the course of the project.

Even in today's "connected" world, rural teachers often feel professionally isolated in the small system in which they grew up as a student and now function in as a teacher. Opportunities for involvement at the state and national levels are deeply appreciated and need to be designed into projects involving rural teachers.

Abstract Title:
Evolution of a Professional Development Program to Promote Effective Teaching

MSP Name: Puerto Rico MSP

Presenter:
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Strand 2

Summary:
The Puerto Rico Math and Science Partnership defines effective teaching in STEM as the practice that generates learning with understanding. We prepare and support teachers to teach effectively through our Authentic Professional Development Program (APDP) which integrates the best teaching practices with math and science content, while performing continuous assessment to promote reflection and metacognition. Our current emphasis is on empowering teachers to train their peers and support them as leaders in their schools. Our APDP includes collaborative evaluation as a strategy that enables teachers to design, implement and evaluate APDP activities for their peers. Our preliminary results suggest that teachers are improving in content knowledge and practices; thus becoming more effective in their roles in their classroom and schools.

Section 1: Questions for dialogue at the MSP LNC

The Puerto Rico –Math and Science Partnership has as one of its goals to improve teacher quality through empowering schools by offering a challenging K-12 Math and Science curriculum and professional development. As we look into the future, *how do we achieve a teaching environment that is predominantly learner- centered? How do we foresee the preparation and development of effective teachers for the 21st century? What are the next steps for the MSP partnerships in this endeavor?*

Section 2: Conceptual framework

We define effective teaching in STEM as the practice that generates learning with understanding. Specifically, we based our definition on specific indicators that make explicit the four characteristics that learners who attain understanding are expected to show, namely, *to be able to construct relations among concepts and ideas, extend and apply their knowledge, justify and explain what they know* and *make knowledge their own* (Carpenter et al.,2004). Our project, AlACiMa (for its Spanish acronym), prepares and supports teachers to teach effectively through our professional development program whose principles include the integration of best teaching practices to math and science content while performing continuous assessment to promote reflection and metacognition. As the project progressed, we added to our conceptual framework attributes of effective learning environments: *learner centered, knowledge centered, assessment centered, and community centered* (Donovan, Bransford, & Pellegrino, 2000) to generate what we call the AlACiMa Authentic Professional Development Program (APDP). The APDP model includes these fundamental aspects: (1) *focus on student learning, (2) deepen conceptual understanding of science and mathematics*, (3) *create a well-defined image of effective classroom learning and teaching*, (4) *engage teachers as adult learners employing learning strategies that can be used with their students*, and (5) *collaborate with peers and experts to improve practice*. The APDP curriculum is focused on inquiry-based model lessons developed and aligned to the Puerto Rico Department of Education's Science and Math Standards, showing the focus on a learner-centered classroom. Our design includes the implementation of the APDP at 27 schools throughout Puerto Rico that were transformed into Professional Math and Science Research Centers (PMSRC).

Our project's original design was to offer APDP to promote effective teaching, and consequently student's learning and understanding of STEM concepts, to over 1,500 teachers in 155 schools. Once our initial funding period concluded (2003-2008) we have focused our professional development program in a smaller number of teachers from eight PMSRC (i.e., resource teachers). For this cohort we are using a train-the-trainer model. Our goal is to empower these resource teachers to train (i.e., capacitate) their peers in our APDP and support their role as leaders in their schools. We have added collaborative evaluation as a strategy to our APDP for this cohort of teachers since we understand that this process will allow them, as capacitators, to design, implement and evaluate professional development activities for their peers. Ultimately, this process will enable them to teach more effectively to their students as it will allow them to have the confidence and skills to develop activities that promote learning with understanding and reflect often on their practice and their students' learning.

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Section 3: Explanatory framework

We will focus on the findings obtained with our intervention with the last cohort of teachers during the last two years. We will present our results on: *resource teacher's learning, transfer of best educational practices to the classrooms, quality of the math and science capacitations* and *student achievement.*

- **Resource teachers' learning**. Pre/post measures on teacher learning in the professional development activities indicate that on most of the capacitations there was generally a considerable improvement in the percentage of correct answers given by teachers. Nevertheless, there was also room for improvement in the content learning addressed.

- **Transfer of best educational practices to the classrooms.** Data regarding the use of these practices by science and math resource teachers was obtained at baseline and at the end of the 2^{nd} year of the project's implementation. Both groups of teachers, but especially the math teachers, showed an increase in the usage of evidence-based teaching/learning and assessment practices for the period studied. Notably, both groups showed increased use of practices emphasized in the project and modeled in the capacitations. This finding is encouraging since it suggests that teachers are increasingly incorporating best practices not only in the capacitations they offer to other teachers (in which they usually imitate what was modeled to them), but in their own classrooms. Teachers also showed changes in their attitudes toward the learning process or school conditions. In the 2011 administration, the teachers tended to express agreement toward the statements posed, suggesting that, at the present time, they have positive attitudes toward the educational process and evaluate positively their school conditions for math and science teaching, although there is still some room for improvement.

- **Quality of the math and science capacitations.** Quantitative results from post-activity reaction forms indicate that math and science teachers who attended capacitations provided by the resource teachers were very satisfied with the training sessions. They gave very high ratings to items that assess the organization, the attainment of objectives and the educational environment of the sessions. Their qualitative comments suggest that the participants were able to identify attributes of effective learning environments in the capacitations carried out by the resource teachers and are planning to implement them in their classrooms. Moreover, second-year results were higher than those observed the 1st year. This finding suggests that the resource teachers are improving in their role as professional development trainers, as assessed by their peers. Improvements in the performance of math and science teachers (participants) were observed in the pre/post assessment of learning in the capacitations provided by the resource teachers. These results were discussed with the teachers/trainers and they reflected on how to continue improving teacher learning and its evaluation in their capacitations. We consider that these results are probably due, not only to the experience accumulated by resource teachers as trainers, but to the reflection sessions in which they reviewed and reflected on evaluation results in the collaborative evaluation sessions.

- **Student achievement**. Data from the PPAAs (standardized tests administered in the Puerto Rico public school system) from Spring 2009 and 2010 administrations in the eight center-schools participating in this last cohort of the project was compared. The percentage of students who scored at or above proficiency increased for all tested grades and subject matters from 2009 to 2010 in the eight participant center-schools. This is an encouraging result because, although it cannot be totally attributed to the impact of the project, it probably contributed to it. Moreover, the eight participant center-schools, when compared to all schools in the public educational system, show higher percentages of students who scored at or above the proficiency level in all tested grades and in both mathematics and science.

During this year, resource teachers will design a professional development session by themselves (not replicate what was modeled by capacitators as was done before) with the support of the STEM and Education faculty as part of their APDP. Our expectation is that our teachers/trainers will offer these sessions to their peers as part of the professional development that other math and science teachers will receive during Summer 2012.

Section 4: Lessons learned

After years of intense teacher professional development to promote effective teaching in STEM at the K-12 level, our experience concur with research indicating that professional development experiences need to be in-depth and of sufficient duration to be effective. We learned that it would have been better to start with a more extensive series of capacitations for the teacher capacitators (i.e., STEM faculty and exemplary 7-12 teachers) to help them incorporate attributes of effective teaching into their capacitations. This would be one that included design and small scale delivery of content-centered science and mathematics activities framed in the AlACiMa model dedicating time to the collaboration skills that are an integral part of that model. Secondly, these PD activities would be built around a relevant theme from the beginning as it is currently done. Finally, we would have adopted the train-the-trainer model for the resource teachers earlier in the project as we have seen that they learn better (content) when they have to teach/ train their peers, and they are better able to plan, implement and evaluate the best teaching practices to promote learning with understanding.

Abstract Title:
Professional Learning Communities: A Vehicle for Preparing, Supporting and Sustaining Effective STEM Teaching

MSP Project Name:
College Ready in Mathematics and Physics Partnership

Presenters:
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Gay Stewart, University of Arkansas

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Strand 2

Summary:
This session describes the iterative process of implementing PLCs across the College Ready in Mathematics and Physics Partnership. PLC concepts and practices for effective implementation have been the unifying link across Partnership activities, building to the launch of PLCs during the 2011-2012 academic year. Initial findings have revealed the need for a precise definition of and expectations for PLCs in the MSP; that a knowing-doing gap exists in educational leadership; and that training for PLC facilitation is lacking. These findings have resulted in numerous changes in how the Partnership has systematized activities to support PLC implementation in partner schools. This session will include further explication of specific challenges and in-progress solutions relating to the implementation of PLCs in *College Ready*.

<u>Section 1: Questions for dialogue at the MSP LNC</u>
How can PLCs be utilized as a vehicle for engaging core partners in activities that increase Partnership sustainability?

What policies and procedures can be instituted to encourage PLC implementation among core partners?

<u>Section 2: Conceptual framework</u>
The College Ready in Mathematics and Physics Partnership is a targeted MSP project that spans multiple geographical regions across two states and includes 39 core partner districts, ranging in size from below 300 to above 18,000 students, two university core partners, and numerous supporting partners in both industry and education. The mission of *College Ready* is "to enhance mathematics and physics learning for all students in its partner districts and teacher-preparation programs in partner institutions, closing achievement gaps, and preparing students for success in mathematics, science, and teaching careers. This will be achieved by building learning communities of 7-12 teachers and college faculty that foster and nurture smooth access to, productive disposition toward, and preparation for success in college."

The *College Ready* vision statement holistically defines “effective teaching in STEM” as beginning with teachers who are “well prepared in content and pedagogy, enthusiastic about their craft, committed to continual improvement, and who work effectively and enthusiastically together to implement an inquiry-based curricular program for all students” (*College Ready* Vision Statement, 2008). Effective teaching will result in STEM classrooms in which students are “actively engaged in meaningful experiences that are built around significant mathematics and physics content; that enable students to explore, reflect, interact, and build meaning that enhances conceptual understanding; and that promote habits of mind that foster an inquiry approach to learning” (*College Ready* Vision Statement, 2008).

In order to prepare and support teachers and faculty to teach effectively, *College Ready* has adopted Professional Learning Communities (PLCs) as the mechanism for institutionalizing instructional changes intended through professional development workshops, as well as for providing the sustainable structure that will extend the impact of *College Ready* activities into the future (Stoll, Bolam, McMahon, Wallace, and Thomas, 2006). Fulton, Doerr, and Britton’s (2010) meta-analysis of PLC research conducted since 1995 indicated participation by STEM teachers in PLCs resulted in positive changes in teachers’ content knowledge, preparation to teach content, and confidence in using varied instructional strategies. Fulton, Doerr, and Britton also found that STEM teachers’ instructional practices were positively influenced by PLC participation, including increased utilization of reform-oriented practices; focus on student thinking during instruction; and engagement of students in problem-solving through various instructional methodologies. While much can be gleaned from the literature regarding the impact of PLC participation on teachers and instruction, research is “emergent rather than definitive” in empirically establishing a causal relationship between teacher involvement in PLCs and increased student learning and achievement (Fulton, Doerr, & Britton, 2010, p. 8).

College Ready utilizes a three-year cohort sequence to develop Master Teachers in mathematics and physics who serve as teacher leaders at their respective campuses. In recognition that efforts to increase college readiness in STEM must be systemic from junior high school to high school, Mathematics Master Teacher workshops include teachers in courses ranging from seventh-grade mathematics through AP-level courses in calculus and statistics, while the Physics Master Teacher workshops are designed for teachers in science courses that include physical science strands spanning the seventh-grade level through AP physics teachers in high school. With the structural diversity found in core partner schools, PLCs are ideally suited for customizability to connect teachers both horizontally at the course level and vertically along the content continuum. Horizontal and vertical teaming sessions have been utilized within all Master Teacher workshops to guide participants through the process of engaging in content-driven discussions and curriculum development, as these collaborative sessions have been designed to enhance participants’ capacity to function effectively as a member of a high-performing PLC.

During the first three years of *College Ready*, PLC concepts and practices for effective implementation have been the unifying link across Partnership activities, building to a systematic launch of PLC implementation across the Partnership during the 2011-2012 academic year. Although PLC constructs have been incorporated throughout Master Teacher Workshops, administrators’ workshops, Steering Committee meetings, and university faculty workshops, PLC-specific workshops were held during summer 2011 to engage teachers and administrators from core partner districts in the nuts-and-bolts aspects of developing new and enhancing existing PLCs in their schools. Intentionally designed to focus on their specific roles in PLCs, administrators and teachers participated independently in workshops that created synergism through the utilization of common instructional resources and activities. A set of video vignettes were used with both groups in their respective workshops, as these vignettes provided participants an opportunity to observe PLCs operating at varying levels of effectiveness. In concert with the vignettes, participants were introduced to a "PLC Efficacy Rubric" that can be used to guide PLC implementation. The PLC Efficacy Rubric incorporates a four-point scale ranging from "1-Little or No Development" to "4-Achieving" and includes five dimensions that are indicative of high-performing PLCs: shared vision, collaboration, reflective dialogue, administration, and depth of change. The primary objective of using the video vignettes with the PLC Efficacy Rubric was to actualize PLCs, which can be a fairly ubiquitous concept, while engaging participants in learning how to observe, critique and provide feedback (administrators) or self-assess (teachers) the efficacy of individual PLCs.

To continue facilitating the developmental progression of PLCs, *College Ready* faculty and staff are conducting campus-level site visits to core partner schools to observe the classroom instruction of *College Ready*-prepared teachers and to engage teachers and administrators within the context of PLC meetings. Although we are in the initial stages of making these targeted visits, a number of substantive decisions for the Partnership have resulted from the observations of and interactions with teachers and administrators during these visits. Campus visits should also directly influence the level of engagement of PLC workshop participants during the upcoming fall and spring follow-up workshops that are designed as check-points to measure PLC progress and to reinforce the PLC concepts and expectations of *College Ready* that were established during the PLC Workshops in summer 2011.

College Ready recognizes that quality professional development, regardless of content or pedagogical focus, must be ongoing and job-embedded in order to have the level of impact required to institutionalize improvements in STEM teaching and learning. Based on the successes of our first PLC Workshops, *College Ready* is expanding our PLC Workshop opportunities in years four and five of the Partnership by doubling the number of workshops being offered and by increasing the depth of content that will be the focus of newly-developed workshops slated for summer 2012. The commitment of resources to these efforts validates the priority placed by *College Ready* on supporting the development of PLCs as a mechanism for enhancing the effectiveness of STEM teaching in our core partner schools, which will lead to greater levels of student college readiness in mathematics and physics and will increase the likelihood of college success for all students.

Section 3: Explanatory framework

One of the primary findings during the first three years of *College Ready* activities was the multiplicity of definitions and conceptualizations of PLCs across the Partnership. Because of the expansive nature of the Partnership, there is no "one-size-fits-all" version of PLCs that can be adopted. Therefore, *College Ready* has not mandated how school partners should configure their PLCs. This autonomy in PLC structure to meet partner needs has been both beneficial and problematic, because it has hindered the development of a cohesive definition of what PLCs are within the construct of *College Ready*, as how an institution defines the concept or problem will directly influence the types of solutions that are developed in response. Although unable to specifically require how PLCs should be structured, *College Ready* is well-aware of the need for a precise definition of what PLCs are, how PLCs should function, and what expectations exist that promote PLC efficacy across the Partnership. These elements were clearly delineated through the PLC Workshops conducted in summer 2011 (as mentioned above) and *College Ready* is working to increase the depth of engagement with these PLC concepts between and among core partners in our efforts to prepare and support more effective STEM teaching.

Another finding related to implementing PLCs effectively in *College Ready* is that a knowing-doing gap exists in educational leadership. The idea of PLCs has been floating around education for decades, which has resulted in most administrators knowing about PLCs, but in our experience, many administrators have an insufficient conceptual understanding of how to make PLCs work at the campus level. To close this knowing-doing gap *College Ready* has enhanced administrator support by increasing the focus on the functional components of PLC implementation, providing instruction and resources that systematically guide administrators through processes that will facilitate the development and ongoing support of high-performing PLCs in core partner districts in *College Ready*.

Our research experience with PLCs has also highlighted the important role of the facilitator within the PLC structure. The PLC facilitator has the responsibility of sustaining high levels of meaningful discourse during PLC meetings, maintaining focus on aspects of teaching and learning, and providing accountability for the group. However difficult these tasks are to accomplish in peer-facilitated PLC settings, an effective facilitator is essential for building and sustaining a PLC that results in the improvement of STEM teaching and learning. The issue within *College Ready*, albeit not exclusive to this context, is that few teachers and/or administrators have received formal training in PLC facilitation. In response to this need, *College Ready* will be providing PLC workshops in 2011 and 2012 that will provide participants with the requisite tools for effective facilitation of PLCs. We will collaborate with partner schools to identify those teachers who are or who will be serving in the facilitator role and will target those teachers for participation in the PLC Facilitator workshop. Workshop content will incorporate research-based best practices for PLC facilitation and will be heavily influenced by the research being conducted in the MSP “Project Pathways: Opening Routes to Math & Science Success for All Students” at Arizona State University.

In order to measure the efficacy of PLCs operating in *College Ready* partner schools, a variety of methodologies are being incorporated into our research design. Data collection from all partner schools on PLC activities will be accomplished through a combination of site visits to at least half of the core partner districts and focused telephone interviews with the remainder of the core partners. During these site visits, evaluators will observe PLC meetings and will utilize an internally developed rubric to measure the effectiveness of the PLC. Data from these site visits will be aggregated at the Partnership level to gauge overall efficacy of PLCs across the Partnership. Additionally, teacher-level survey data regarding *College Ready* impact on PLC development and implementation have been collected and preliminary analyses are being conducted. Follow-up surveys will be administered in 2012 and a comparison of survey responses will be analyzed. During year 4 of *College Ready*, the “Facilitator Observation

Protocol" developed at Arizona State University will be incorporated into Master Teacher Follow-up Workshops and professional development activities during summer 2012. This protocol will serve as a metric for evaluating facilitators' effectiveness in engaging PLC participants in "substantive conversations about understanding, learning and teaching" (Carlson, Bowling, Moore, & Ortiz, 2007).

Section 4: Lessons learned

Incorporating PLCs as a vital component to *College Ready* activities was the result of school partner input during the proposal development stage of the Partnership. With PLCs being a partner-driven suggestion, *College Ready* failed to anticipate the lower levels of buy-in for PLC implementation at some core partner districts. The main challenges to increasing partner engagement in PLC development include structural impediments existing within schools, such as time, scheduling, and resource allocation, as well as frequent turnover in campus leadership that can negate or diminish progress toward effective implementation of PLCs. To overcome these challenges, the Partnership is working closely with campus leadership to increase our presence in core partner schools and to encourage *College Ready*-trained Master Teachers in their PLC activities. We are also providing multiple venues for teachers and administrators to share their PLC experiences and to engage with colleagues in substantive discussions about what does and does not work, which includes working around the structural impediments frequently cited as the primary reason for lagging PLC implementation.

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Abstract Title:
Mathematics Studio – a Greenhouse for Growing Mathematics Leaders

MSP Project Name:
Oregon Mathematics Leadership Institute Project

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Strand 2

Summary:
The Mathematics Studio Classroom is a scalable and sustainable model that can transform the professional learning culture in a school. A cohort of teachers, coaches, and administrators meets to learn and rehearse "mathematically productive teaching routines" - practices that are designed to: align directly with how students learn mathematics, recur regularly in the everyday work of teaching mathematics, typically involve one or more challenging aspects of mathematics teaching, and enable mathematical access and challenge for all students. Studio work includes planning for implementation of a lesson, a "live" rehearsal of one or more of these routines, observations of the enacted plan, gathering of student data, and analysis of data as evidence about the impact of instructional decisions and lesson design.

<u>Section 1: Questions for dialogue at the MSP LNC</u>

What are the purposes of the math studio?
What happens during each studio cycle?
Who participates in a math studio?
What are the greatest challenges in initiating a studio model in a school?
What are the greatest challenges in sustaining the studio model?
What implications does model have for preservice mathematics teacher education?
How does a school benefit over time from studio work?

<u>Section 2: Conceptual framework</u>

Effective teaching in STEM must center on student thinking, where teacher moves and questions all have one of two purposes in mind – to "push" (student thinking forward) or to "probe" (elicit evidence of how students are thinking).

How Students Learn Mathematics

Drawing on a robust and seminal body of research on how students learn mathematics, all studio related work on instruction emphasizes engaging students consistently in evidence-based learning experiences that involve –

- Cognitively demanding mathematical tasks
- Adherence to mathematically productive classroom norms and relationships
- Productive disequilibrium about mathematical ideas and relationships
- Mathematical discourse that focuses on students' mathematical reasoning, sense making, representations, justifications, and generalizations
- Reflection and metacognition about their own and each other's mathematical thinking.

The studio design is guided by a well-defined, research-based vision of effective mathematics learning experiences for students. This vision is articulated in the following **theory of action:** *Student mathematics achievement will improve if teachers consistently use research-based instructional practices to develop both computational fluency and a deep understanding of mathematics concepts by engaging all students consistently and effectively in the following mathematical practices:*

- ***Providing Explanations*** *– Students explain how they think about the meanings of ideas and the mathematical reasoning they use to make sense of calculations, problems, and/or ideas.*
- ***Making Justifications*** *– Students use mathematical reasoning (both inductive and deductive) to justify why their own or others' ideas are or are not valid/accurate. They identify relevant and age-appropriate mathematical definitions, properties, processes, counter examples, and/or established generalizations to present a robust logical argument and demonstrate precision.*
- ***Formulating Conjectures & Generalizations*** *– Students make and test conjectures and generalizations about the application of their own and others' mathematical ideas and processes to the general case, special cases, and/or different contexts.*
- ***Using Multiple Representations*** *– Students make, use, and connect multiple mathematical representations – equations, verbal descriptions, graphs, concrete models, charts, tables, everyday life situations, and diagrams – to "mathematize," make sense of, solve, and/or communicate about the questions, quantities and relationships in problems and ideas.*
- ***Engaging in Metacognition*** *– Students practice mathematical metacognition by reflecting about: (1) what/how they think about a math idea or problem; (2) disequilibrium, breakthroughs, and "stuck-points" in their thinking; (3) ways their mathematical understanding is developing; and (4) specific ideas or learning episodes that influenced their thinking.*
- ***Making Connections –*** *Students make and discuss connections between their prior understandings and the new mathematical concepts and skills they are learning, between their thinking and others' ideas, and between the mathematics they are learning and other contexts/content. Bransford et al, 1999; Cohen, 1994; Donovan & Bransford, 2005; Franke et al, 2007; Kilpatrick, 2001; Lotan, 2003, 2006; Stein et al, 2000; Common Core State Standards Initiative, 2010*

Mathematically Productive Teaching Routines

Work in the studio school emphasizes the planning and rehearsal of several specific research-based teaching practices that meet criteria for "mathematically productive" because they:

- engage students in activity that aligns directly with how students learn mathematics
- recur regularly in the everyday work of teaching mathematics
- typically involve one or more challenging aspects of mathematics teaching

- enable mathematical access and challenge for all students

Because of these features, a teacher's repeated use of such practices will leverage mathematical sensemaking, understanding, and proficiency by all students, and will carry over into other aspects of the teacher's practice. (*Franke, 2008; Franke & Kazemi, 2009; Ball, 2008; Marzano, 2006, 2009; Ghousseini, Lampert, et al, 2008; Weiss et al, 2003)*

Mathematical Discourse
An evidence-based premise of the studio work is the notion that orchestrating productive mathematical discourse increases students' opportunities to learn and, in turn, raises achievement and participation levels in mathematics. Embracing this premise requires developing teachers' knowledge, skills, tools, and disposition for building classroom communities of mathematical discourse. (*Leahy, Lyon, Thompson, and Wiliam, 2005; Yackel & Cobb, 1996; Hufferd-Ackles & Sherin, 2004; Stein, Engle, Hughes & Smith, 2008; Weaver & Dick, 2006)*

Specialized Mathematics Content Knowledge
In order to orchestrate purposeful and mathematically productive discourse, teachers need a deep understanding of the math content they teach and its trajectory over time. Whether in a related Knowing Mathematics for Teaching course or during a studio day, all studio work emphasizes deepening teachers' knowledge of the content needed to effectively teach mathematics. (*Ball, Thames and Phelps, 2008; Ball, Hill and Bass, 2005)*

Cognitive Demand
Not all math tasks are "discourse worthy." The Math Task Framework and the role of cognitive demand in student learning provide a theoretical underpinning for identifying and designing high-cognitive tasks, and a basis for planning and analyzing "live" studio enactments of those tasks. (*Stein, Smith, Henningsen and Silver, 2009; Bloom, 1956)*

Professional Learning Community & Student Achievement
Built into the design of the studio program are research-based features of professional community that correlate positively to student achievement. A primary focus of all mathematics studio work is transforming the culture of mathematics professional learning across each studio school. (*Boaler, 2006; DuFour, 2009; Little, 1990, 2000; Louis et al, 1996; McLaughlin & Talbert, 2001, 2006; Weaver & Dick, 2009)*

Generative Learning
Teachers learn to attend relentlessly to their students' mathematical thinking. Administrators learn that understanding students' mathematical thinking is central to effective teaching, and they learn to support teachers in developing the norm of being curious about students' mathematical thinking – the single most important factor in developing into a teacher who continues to learn. Students develop metacognitively – learning to attend carefully to their own mathematical thinking and relationships to others' thinking. Through this process, learning becomes self-generating for students, teachers, and administrators, who continually add to their understandings. (*Franke, Carpenter, Levi, & Fennema, 2001)*

Formative Assessment

A teacher's relentless focus on understanding students' mathematical thinking is also fundamental to formative assessment – a practice that shows an effect size larger than most known educational interventions. In particular, formative assessment is especially effective for students who have not done well in school, thus narrowing the gap between low and high achievers while raising overall achievement. (*Black et al, 2004; Wiliam, 2007)*

Lesson Study
The studio model applies elements of Japanese lesson study in that teachers collaboratively plan, observe/enact, and analyze a lesson. While contextualized in deep planning, unlike lesson study, studio work focuses teachers' attention on public work with students as a way to rehearse and refine evidence-based mathematically productive teaching routines – i.e., emphasis is on polishing practice vs. polishing a whole lesson. (*Stigler & Hiebert, 1999; Lewis, 2006; Watanabe, 2003; Lampert et al, 2008; Kazemi & Franke, 2009)*

Effective Professional Development
By design, all studio-related work aligns tightly with the research-based characterization of effective professional development as:

- intensive, ongoing, and connected to practice
- focused on students' learning
- supportive of teachers while they rehearse teaching in "real time"
- designed to align with local school goals and priorities and other initiatives
- focused on the development of strong working relationships among teachers

The studio program embodies all five of these principles in a structured way that is sustainable for the long-term within a school. (*Darling-Hammond et al, 2009; Stiles et al, 2009; Franke et al, 2001; NSDC, 2001)*

Powerful School Leadership
Focusing on the school as the "unit of change" and a distributed view of leadership requires specialized learning for principals and district administrators, who receive coaching to develop their leadership voice for mathematics, organize their school for mathematics learning, and analyze mathematics teaching. (*Elmore, 2002; City et al, 2009; Nelson et al, 2005; Lambert, 2003; Grant et al, 2009)*

Section 3: Explanatory framework

In order to understand and prepare for dissemination and application of the Mathematics Studio model at scale, we are currently seeking better understanding of the active ingredients of the model. Hence, we are seeking, creating, refining, and studying tools and structures that will be readily adaptable to other contexts and by other professionals from the field. This currently includes the following evidence-based tools that relate directly to our theory of action and that are in various stages of development.

- *Mathematically Productive Leadership Routines* that support principals and district office administrators in learning and internalizing effective leadership practices.
- *Mathematically Productive Teaching Routines* that support teachers in learning and internalizing effective instructional practices.
- *Mathematically Productive Thinking Routines* to support students in learning and

internalizing evidence-based mathematical habits-of-mind and habits-of-interaction that yield mathematical conjectures, generalizations, and justifications by all students. Hence, students who develop these habitual patterns of thought and interaction develop the habits of practice used by successful mathematicians, as described by the *Common Core State Standards*.

- Classroom observation instruments for measuring the quantity, quality, and growth in students' mathematical conjectures, generalizations, and justifications.
- Implementation rubrics that measure fidelity of implementation and impact on practice (leadership, instructional, and/or mathematical) of each *Mathematically Productive Leadership* and *Teaching Routine*.
- Surveys for teachers, administrators, and students, designed to promote reflection and generate self-report data about progress related to achievement of the Mathematics Studio goals.
- Interview protocols that focus on the Mathematics Studio model's affect on a teacher's knowledge of their students' mathematical thinking, mathematics content, and mathematics pedagogy.

Section 4: Lessons learned

When the Mathematics Studio model takes root in a school, as evidenced by student data, the school becomes a living "greenhouse" for seeding expansion of the studio model. Cohorts of teachers and administrators from other schools/districts attend the greenhouse studio to develop readiness for launching their own studio work. Pre-service teachers and their supervisors from local universities are Residents in selected greenhouse studios. Teams of administrators form "leadership studios" in the greenhouse school, focusing on planning, enacting/rehearsing, and debriefing specific math leadership strategies. Mathematics coaches and other teacher leaders use the studio school as context for developing their leadership skills in "real time" with teachers and students. Researchers use the greenhouse studio school as context for a variety of research agendas (e.g., the ecology of the school, mathematics learning and teaching, issues of equity, leadership and organizational change). Whether growing classroom by classroom, school by school, across a K-12 feeder pattern, or district to district, the studio model shows promise as attainable and scalable through thoughtful organization and allocation of resources.

A supplement to the OMLI grant and NSF/Noyce program funding have supported the use of the Mathematics Studio model as context for supporting the development of Noyce program "Master Teaching Fellows." After three years of NSF-funded studio work, these teacher leaders are now leading studios in their own and other high needs schools, the transformation of the culture of mathematics professional learning is evident, and student achievement is on the rise. Our session will highlight the impact of the Studio work on these Fellows' classrooms and schools, and ways that learning from work in their classrooms/schools has informed the design/implementation of the Math Studio model in other sites.

Abstract Title:
Use of Multiple Stragegies and Processes: Preparing Teachers and Faculty to Teach Effectively

MSP Project Name:
TASEL-M Phase 2

Presenters:
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Strand 2

Summary:
“Effective teaching in STEM" relies on the support of "learning" for each student by motivating and engaging them in mathematics. In order to address these varying aspects, Teachers Assisting Students to Excel in Learning Mathematics: Phase II (TASEL-M2) approach content delivery; best practices and assessment; a structure for lesson design; and strategies that support student struggles in learning mathematics. A cohesive plan that brings all teachers and faculty members together within a school or district with a common cohesive approach will increase mathematics knowledge for each student to learn at their highest potential. In addition, through the years, this process will support students in the school and district.

Section 1: Questions for dialogue at the MSP LNC

- How do you get all teachers to buy in?
- How do you get administrator support?
- How do you involve STEM IHE?
- How do STEM IHE bring ideas back to the IHE?

Section 2: Conceptual framework

The definition of “effective teaching in STEM” needs to address support of “learning” for each student by motivating and engaging them in mathematics. In order to address these varying aspects, *Teachers Assisting Students to Excel in Learning Mathematics: Phase II (TASEL-M2)* approach content delivery; best practices and assessment; a structure for lesson design; and strategies that support student struggles in learning mathematics. A cohesive plan that brings all teachers and faculty members together within a school or district with a common cohesive approach will increase mathematics knowledge for each student to learn at their highest potential. In addition, through the years, this process will support students in the school and district.

The design for *Teachers Assisting Students to Excel in Learning Mathematics: Phase II (TASEL-*

M2) to prepare and support mathematics teachers and faculty to teach effectively engages full mathematics departments in cohesive strategies through *Gradual Release of Responsibility (GRR)*, *Professional Learning Communities (PLCs)*, *Cycles of Professional Inquiry (CPIs)*, and *Pedagogical Content Knowledge (PCK)*. All teachers in each middle school and high school mathematics department are provided workshops in *GRR*, *PLCs*, *CPIs* and *PCK*. All Principals, department chairs, and coaches across all content areas are provided with support to work with teachers at individual sites through specific training in *Cognitive Coaching* and *Adaptive Schools*. This strategic program provides the same level of understanding around *PLCs* and how to support the *GRR*, *CPIs*, and *PCK* throughout the year. By building common and cohesive knowledge of these various processes for teaching and learning, teachers are given strategies to be most effective in creating optimum learning.

Faculty are prepared and supported through the project by their involvement in the same processes as they work in partnership with their Teacher on Special Assignment (TOSA). Faculty Partners also work together as a team to incorporate these same strategies and processes within their IHE remedial math courses. They have a supportive role with the teachers through the *PCK* sessions, along with additional content support at workshops and other co-plan, co-teach sessions with peer coaches and teachers.

The *Gradual Release of Responsibility (GRR)* is a research-based instructional model developed by Pearson and Gallagher, 1993 to gradually reach all students in the classroom with a scaffold approach to transfer responsibility from teacher to students through the "I do, We do, You do" process. This model is extended in the project to release responsibility from the Teachers on Special Assignment (TOSAs) to peer coaches to the teacher in the classroom as a professional development adaptation of *GRR*. The cognitive workload is shifting from the mathematics teacher, to joint responsibility with students, to student peer collaboration, and then to student independent application.

Professional Learning Communities (PLCs) give all teachers within mathematics departments a venue to come together with common vision, purpose, and goals to support student learning in their mathematics courses. Discussions involve analysis of *California Standards Tests (CSTs)* & benchmark data, and creation of course-alike pacing guides, common lessons, units of study, and assessments.

Cycles of Professional Inquiry (CPIs) give TOSAs, Faculty Partners, and teachers a collaborative forum to create focused mathematics lessons, guided instruction, and independent tasks utilizing the *GRR* process. Practice is provide through a lesson study model for "in-class" support sessions with Demonstration lessons, team planning conversations, *CPI*, and observation and feedback to co-plan, co-teach, review, and revise.

Experience with *Pedagogical Content Knowledge (PCK)* is provided for all teachers by *STEM* faculty to increase awareness of levels of cognition for varying levels of mathematics in each course using evidence of student struggles gained by district benchmark tests that are aligned to the *CSTs*.
Time and support is provided for "in-class" support with modeled mathematics lessons, co-plan and co-teach opportunities, as well as observation and feedback from district mathematics specialists, peer coaches, and STEM faculty.

Section 3: Explanatory framework

TASEL-M2 has focused on one urban district to determine the effects of scaling up a project from two high schools with their feeder middle schools to all high schools and their feeder middle schools. Four Teachers on Special Assignment (TOSAs) work with the Secondary Director of Curriculum. The *Project Leadership Team (PLT)* meets once a month to plan and evaluate all activities, review data, and guide the goals of the grant. Members of the *PLT,* working as a *PLC,* lend support for all stakeholders of the grant. District administrators guide the TOSAs in their work with the Faculty Partners, mathematics peer coaches, department chairs, and classroom teachers.

At the district level, support is provided by the Assistant Superintendent and Co-PI of the grant through the Director of 7-12 Instructional Services who works directly with site administrators. As research indicates, it is important for the site administrator to give full support for *PLCs* and the work of *CPIs*. She also works with the TOSAs to create a comprehensive program and connect their work as a centralized district approach. TOSAs plan all activities in conjunction with the *PLT* to provide coaches and department chairs with training in *GRR*, *Cognitive Coaching*, and *Adaptive Schools* to create a coordinated approach for mathematics teachers at each school in the district. Trainings, "in-class" support, *CPIs*, *PLCs*, and *PCK* are provided to all schools through this systemic approach that connects the district administration, TOSAs, Faculty Partners, principals, coaches, department chairs, and classroom teachers. This systemic approach gives students at all sites equity in delivery, content, and process for learning and success in mathematics.

Resources for effective mathematics teaching involve two main foci; time and money. Time has been provided through the grant to give teachers release time to support their learning at trainings and implementation days for *Cycles of Professional Inquiry (CPIs)*. Teachers also value and ask for more time to collaborate with the *CPIs* and *PLC* continual work. The financial support was necessary to provide trainers for specific workshops in *GRR, Cognitive Coaching,* and *Adaptive Schools* and to cover substitute costs associated with these activities. A percentage of TOSA salaries are covered by the grant, indicating a need to have centralized support by having individuals to create and monitor all work and activities to support all aspects of the project.

One question we hope to answer with Phase II of the project is; In what ways do more established PLCs differ from developing PLCs, or those with minimal PLC training? Since we have three cohorts of teachers engaged in the work: Cohort 1, the original sites that were involved in TASEL-M: Phase I; Cohort 2, the schools that were new to the treatment beginning with Phase II of the project; and Cohort 3, all remaining middle and high schools within the district that began treatment in the second year of Phase II. We are seeing some results with improved *PLC* strength using Professional Networking software.

Section 4: Lessons learned

Several lessons have been learned through our project. We will note a few highlights.

One lesson learned relates to the *Cycles of Professional Inquiry (CPI)* process and the importance to include more "in-class" for teachers to use the strategies more often and more effectively as a normal activity. By using cohesive strategies of *Gradual Release of*

Responsibility (GRR), Professional Learning Communities (PLCs), Cycles of Professional Inquiry (CPIs), and *Pedagogical Content Knowledge (PCK)* teachers are now focusing on teaching students until they "get it".

There are two struggles with the design. Having all coaches feeling they are adequately prepared and able to coach their colleagues is challenging. Coaches struggle with finding time to do coaching when they do not have additional time set aside to allow them to fully implement what they have learned. They often feel they could do more if they had some time given to the task, or, at least compensation for the additional work. Department chairs are elected within their departments and may or may not be the coach. When they are not the coach who has the additional training, they may not utilize their coach to build the culture for *PLCs* and *CPIs* as regular practice. Additionally, the principals are a key factor in creating the culture for reception of the change for all teachers in the department. According to Fulton, Doerr, and Britton (2010) in their report, *STEM Teachers in Professional Learning Communities: A Knowledge Synthesis.* "Principals must also do some level of monitoring to ensure that real PLC work is happening . . . 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" (p. 41). This is an area we are working with more closely this year.

A key lesson learned in *TASEL-M2* is the value of social network analysis (*SNA*) in studying the development of *Professional Learning Communities (PLCs*). In response to discussions at the *2010 LNC*, *TASEL-M2* developed a method of assessing growth and change in *PLCs* that focuses at the network level, rather than the individual level. By focusing on *PLCs* as units, the project was able to describe what it means to be a high-functioning *PLC* in concrete, measurable ways. Data from the SNA sociograms also were used in professional development with teachers as a kind of formative assessment tool. Given that *PLC* development has been a central focus of the project, this advance in measuring and talking about *PLC* quality has been a significant change.

Abstract Title:
Building a Mathematics Coalition

MSP Project Name:
Algebraic Concepts for Elementary Students (ACES)

Presenters:
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Strand 2

Summary:
ACES has constructed and continues to deepen and broaden a coalition of partners who support one another in enhancing mathematics learning in grades 4-8, with the ultimate goal of having students succeed in algebra, and be well-prepared for advanced mathematics classes. The partners include teacher-teams, district administrators, county specialists, education faculty, natural science faculty, and the project evaluator. We will discuss how *ACES* is creating true and long-lasting partnerships which involve mutual trust and respect, and how these are influencing professional development, lesson study teams, and mathematics instruction. District and University personnel identify strengths of highly effective teachers, and ways to enhance pre- and in-service teacher education. The web of collaborative relationships strengthens P-18 articulation and instruction at all levels.

Section 1: Questions for dialogue at the MSP LNC
How have we created a coalition of teachers, site administrators, district administrators, county specialists, natural sciences faculty, and college of education faculty in support of effective mathematics teaching?

1. How do we build consensus among project personnel from all areas in defining and increasing “effective mathematics teaching”?
2. How do we encourage teachers to move from grade-level focus to a broader view of mathematics?
3. How do we address the disparities in mathematics and pedagogical background of a large group of teachers?
4. How does our research and evaluation design support the partnership development and how does the partnership support research and evaluation?

Section 2: Conceptual framework
Algebraic Concepts for Elementary Students (ACES) has proposed the following vision: to create and sustain Professional Learning Communities of teachers and administrators who work

collaboratively through lesson study, seminars, and summer institutes to provide high quality instruction and continuously improve mathematics instruction. These improvements will result in significant gains in student learning and achievement among elementary and middle school students, gains that will be sustained in high school and beyond. **By "high–quality math instruction" we mean mathematically accurate, engaging, focused on student learning; and balanced with regard to conceptual understanding, procedural skills, and problem solving.** Teachers will develop a view of math as exciting and interesting and will gain a broad and deep understanding of the curriculum within and across grade levels. Through *ACES*, we will develop a distributed, classroom-based, cadre of grade-level leaders; classroom teachers who adopt math as their area of expertise and provide math leadership to their colleagues.

<u>Mathematically accurate</u>: Good mathematical content must be at the core of effective mathematics instruction. Effective teachers must have a solid understanding of the mathematics taught in schools, which includes an understanding of how and why it works the way it does. For example, a teacher who is asked by a student "Why is the product of two negative numbers positive?" should be able to give the student an explanation appropriate to his/her understanding; if this is not a complete proof, it should be a stepping stone on the way to a proof rather than an explanation that needs to be set aside in order to understand a proof.

<u>Engaging</u>: Effective mathematics teaching should be interesting to students. The effective mathematics teacher will make the content fascinating and engaging, rather than rote and mechanical. Engagement involves a combination of approaches, such as arousing curiosity about individual mathematics topics, making connections among mathematics topics, and making connections to real world applications.

<u>Focused on student learning</u>: An effective mathematics teacher is constantly engaged in thinking about students' learning - typical questions a teacher should ask him/herself might be: Are all students benefiting from the lesson? Is students' understanding of mathematics expanding with each lesson? What misconceptions are students exhibiting, and how can I address them? Is my instruction appropriate for my audience? What adjustments should I make to accommodate specific needs such as those of English Learners, different learning styles, and so on? How does my instruction build on past content, and how does it prepare students for future learning of mathematics? This teacher will listen carefully to students' statements and questions, and help each student move forward from the place in which he/she is mathematically.

<u>Balanced</u>: There are many aspects to learning mathematics, and an effective mathematics teacher will balance them all - if not in each lesson, then over time. When our proposal was written, we adopted the California view of balancing conceptual understanding, problem-solving, and basic skills. Since then, the Common Core State Standards have been adopted, and we have expanded (and improved) this view by adopting the CCSS Standards for Mathematical Practice as the underlying structure for determining mathematics practice and balancing instruction.

How does the ACES partnership prepare and support teachers to teach mathematics effectively?

At the core of successful support of effective teachers of mathematics is a <u>strong partnership</u> that bridges the gaps in education and professional culture between IHE and K-12, natural sciences and education faculty, district/site administration and teachers. Although we all have similar goals and <u>seem</u> to speak the same language, we have found that hidden assumptions can create misunderstandings, and that extensive discussions can not only bridge these but also create new and productive understandings. As a result of ongoing discussions and significant time and effort devoted to learning others' culture and viewpoint, we have a continually strengthening partnership which is seeing significant gains in efficacy of instruction even in the second year of the project.

The in-service professional development components of *ACES* are

- Two-week summer institutes, combining content and pedagogy
- Ten lesson study days during the academic year
- Ten (monthly) afternoon seminars during the academic year
- Un-facilitated (paid) collaboration time for each of the teacher teams

Additionally, we have begun to modify the CSUSB pre-service teacher program based on learning from the professional development.

- Student teachers are provided the opportunity to participate in lesson study with *ACES* teams
- The Common Core Standards for Mathematical Practice are being incorporated into mathematics content courses as well as methods courses for both elementary and secondary teachers.

The *ACES* teachers are developing increasingly effective and reflective professional learning communities with lesson study at the core. Prior to *ACES*, the district had begun developing PLCs, but without the structure of traditional lesson study and without a well-defined structure for reflection and modification of teaching based on the reflection. By incorporated a structured reflection component in lesson study, teachers are developing "eyes to see students", and are learning to implement formative assessment in their teaching overall.

As teachers have become more reflective, they have requested a variety of valuable topics for seminars and summer institute. To respond to these requests, we designed the second summer institute as a 2-week conference – with plenary sessions, sessions designed for grade-spans, and parallel sessions on different topics from which teachers were able to choose those in which they were most interested.

With university faculty involved in all aspects of the project, they are learning a great deal about K-12 teaching, see implications for their own university teaching, and are able to modify university teaching in ways that were not originally anticipated. For example, we conduct monthly "content leadership" meetings, which have become a joint university-K-12 learning community of practitioners and researchers. One of the consequences has been a conscious effort to incorporate Standards for Mathematical Practice into university teaching of mathematics and mathematics methods.

The increased synergy between all partners in this project, and the effects of the collaborative work, truly prove that the whole is greater than it's parts!

Some of the ingredients of successful support of effective teaching are

- Making the project an opportunity rather than an obligation; teachers were accepted into the program in teams, after having completed a team application and interview.
- Releasing control - allowing significant portions of the project content to be determined by the teachers. These include lesson study and unfacilitated teacher collaboration time.
- Creating a safe space for teachers to develop and explore their interest in learning about student thinking, which then leads to a desire to gain a deeper understanding of mathematics so as to assist students in rising to a higher level of thinking.
- Supporting risk-taking among the project teachers; this involves both direct support of the teachers' learning and teaching through project activities, and support of principals to allow them to allow their teachers to take risks in their teaching.

For sustained impact, we have incorporated additional aspects:

- *ACES* works directly with approximately sixty teachers out of 1200 in the district. An important component of what we do is to encourage a ripple effect among the teaching staff of the district, and encourage *ACES* teachers to take leadership roles and to share the project activities with their colleagues. The leadership roles may be formal (e.g. department chairs, textbook adoption committees, lesson study leaders, and so on) or informal, e.g. providing resources for teachers and administrators in transition to CaCCSS (California Common Core State Standards.)
- Make the lesson study work an extension of the existing district Professional Learning Community (PLC) and congnitive planning foci; thus more and more of the school PLCs are expressing an interest in using spending their collaboration time in lesson study.
- A gradual process of transfer of leadership of lesson study teams from *ACES* facilitators to site teachers. This process is happening at a difference pace in each of the teams, as the team teachers have different leadership skills and varied abilities and experiences in teamwork. However, the *ACES* facilitators engage in ongoing conversations on how to make this transition a successful one for all teams.
- There is a two-way process of alignment of ACES and Ontario-Montclair School District (OMSD) goals and processes:
    - *ACES* work is being incorporated into the district strategic plan in various ways, for example use of the MARS assessments as a means to increase formative assessment and transition to CCSS-style assessments
    - OMSD strategic foci are incorporated into ACES work. The district has five such foci: professional learning communities, English language development, writing across the curriculum, standards-based instruction, and response to Intervention.

Underlying and supporting all of this work are multi-level and multi-institutional partnerships that are continually being strengthened:

- Leadership from CSUSB, OMSD, SBCSS, and the evaluator
- Within CSUSB, between the Mathematics and the Education faculty
- Teams of teachers who collaborate in lesson study and in seminars/institutes

- A beginning of creating student learning partnerships through collaborative work in the classroom

***In this session** we will discuss how our web of nested partnerships support the components of effective mathematics teaching as described above.*

Section 3: Explanatory framework

The two lists in the previous section (ingredients of successful support of mathematics teaching, and aspects incorporated into the project) are a combination of beliefs in place before beginning the project, and beliefs we have developed or enhance through project work. Additionally, some additional aspects have arisen during our work in the project:

An important role in learning from project activities is played by the research and evaluation team. Using a mixed methods approach, the R&E design involves collecting a wide variety of data regarding *mathematics knowledge for teaching* (via annual LMT and MARS teacher assessments, lesson study facilitator debriefings and reflections on lesson study sessions), *attitudes of teachers and students to mathematics and learning mathematics* (via written surveys supplemented by selected interviews), *teaching behaviors over time* (via observation of lesson study planning, research lesson implementation, and debrief sessions), *student outcomes* (using state standardized testing and formative assessments), *ability to reflect and to apply formative assessment* (via lesson study reflections and videos), *refinement of the ACES professional development model* (via observation, interviews, facilitator debriefs and participant surveys), and on the *evolution of the ACES partnership* (which includes social network analysis of partnership infrastructure development). Data retreats each semester as well as data reflection events integrated into project management and team meetings to build our capacity to use data to improve the project formatively over time.

<u>Partnership and Bridges</u>: As we have worked together on the various and complex aspects of the *ACES* project, we have developed an increasingly deep appreciation of the value of partnership. Partnership was at the core of the original grant proposal, and the various partners in the project have worked together collaboratively previously - but with the long-term, close, and deep collaboration of the past year and a half we have developed a much richer understanding of what can be accomplished through a multi-faceted and nested complex of partnerships such as we are developing in *ACES*. An important role in this development is played by a Teacher on Assignment who was hired by *ACES* to provide a bridge between the cultures and disciplines of University, District, Natural Sciences, Education, and so on. This role was not envisioned in the original grant proposal, and was added to the project as a result of perceived need.

<u>We - and the project teachers - have learned that time is important for effective teaching in multiple ways:</u>

- Effective teaching requires a great deal of study, preparation and planning. As a result, the lesson study cycles in ACES are growing in length.
- Project staff and district administration need to give teachers far more time than we originally expected to come to conclusions regarding the need for content knowledge and additional teaching approaches and strategies.

- Development of effective, deep, and trusting partnerships takes time, along with a real desire to deepen and expand the partnership.

Choice is important - the more choice and control teachers have regarding their professional development, the more buy-in they have, and so we have increased the number and quantity of choices and opportunities given them.

Increased control of learning - teachers guide content of seminars/institutes/lesson study

Increased responsibility - Currently, the responsibility is manifested in areas such as choice and control described above. We are developing pathways to increased leadership roles within the district for ACES teachers.

We are set up to learn about

- The influence of the professional development on teachers' learning of mathematics, growth in content knowledge with an emphasis on conceptual understanding and problem-solving, collaboration on learning and teaching, and approaches to doing and teaching mathematics
- The effects of changes in teacher attitudes and conceptual understanding of mathematics on teacher learning and on student learning
- The effects of the increased choice, control, and responsibility of teachers on teacher buy-in, self-efficacy, quality of teaching, and quality of leadership
- The process of development of effective lesson study teams of teachers

Section 4: Lessons learned

Note: We interpret "you" in this section to mean all ACES participants: project staff, district personnel, and participating teachers.

Transfer of learning from professional development to classroom practice: We have learned that a teacher needs a great deal of discussion, collaboration, and grappling time before a new concept or strategy can be effectively implemented in the classroom. Implications for project and teacher support:

- Administration needs to provide that time to teachers, rather than expect workshop learnings to be transferred immediately to classroom use.
- Lesson study and un-facilitated teacher collaboration time provide crucial means to accomplish this goal.

Assessment as Opportunity: We see a significant need to assist teachers in viewing assessment as an opportunity to learn about student thinking rather than as an added burden to their already very busy schedule.

Bridges: We learned during the first year of the project that in order to bring together various aspects of the grant and to support teachers in implementing ACES philosophies on teaching mathematics, there is a need for a "bridge" role: someone situated in the district and steeped in district culture who can become conversant with project content and perspectives and help make connections and deepen the partnership, with special emphasis on to teacher support. Having hired a Teacher on Assignment who began working in this role in July 2011, we are already seeing extremely positive results, and plan to maintain this role if at all feasible financially.

Professional Development: It has become clear that seminar or institute professional development is better received when teachers have opportunities both for grade-level (or grade-span) work and for vertical discussions. They have a need to see the implications for their own teaching fairly directly, and then are quite willing to grapple with new ideas and approaches.

Lesson study teams: We have a wide variety of types of lesson study teams - from those with 2 teachers to those with 14 participant teachers, and from those with only one grade level to those with three grade levels. We are learning that almost any combination can work, but that a minimum of 4 teachers is needed for an effective lesson study process. As a consequence, we are combing our two smallest teams to create one with 5 teachers.

Principals' beliefs have evolved ; in the beginning of the project there was a great deal of concern among principals about the significant commitment to the grant required of teachers and administrators, including risking new teaching styles and 10 days out of the classroom for lesson study. Having been through a year of the program, there is now a great deal of support for the process, and patience with a longer processing time. Veteran ACES principals are assisting new principals to find ways to support the ACES process.

Teachers are developing understandings regarding:

- The need to spend time on creating foundation of understanding in the classroom (and they see results)
- The need to listen mathematically to students, to apply math to real world, and to give student true problem-solving situations
- The need for language acquisition in mathematics
- The importance of perseverance in their own learning, and for helping students learn to persevere
- The importance of multiple ways to solve math problems

Abstract Title:
The Poincaré Institute:
Supporting Effective Teaching and Learning

MSP Project Name:
Poincare Institute: A Partnership for Mathematics Education

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Strand 2

Summary:
The Poincaré Institute provides three online courses for in-service teachers. The courses – designed and taught by mathematicians, physicists, and education researchers – focus on the real line and Cartesian plane, algebra and functions, their representation and applications. This presentation will focus on the content and structure of the lessons, on how the courses have evolved taking into account teachers' suggestions and performance, on how we evaluate the impact of the project on teacher development and student learning, and on preliminary data we have collected and analyzed so far.

<u>Section 1: Questions for Dialogue</u>

How can we merge mathematicians’, physicists’, and educators’ perspectives to promote mathematics teacher development and learning of mathematics in schools?

How can we evaluate the impact of a teacher development program on teachers’ ways of teaching?

How can we evaluate the impact of a teacher development program on student learning?

What kinds of activities are more likely to promote shifts in teachers’ approaches to teaching?

Section 2: Conceptual Framework: STEM education and our MSP Project

Effective teaching in Mathematics is teaching that enables student understanding of concepts and fosters their ability to apply them to science and practical problems. In order to achieve these objectives, teachers themselves should have a deep understanding of the subject matter that goes well beyond the lessons they teach. They should be able to see the links between the different topics in the curriculum and also between the Mathematics curriculum and the Science curriculum. They should also be able to understand their students' thinking and should be encouraged to listen as much as possible and to ask questions that promote learning.

The project therefore rests on the premise that, to improve mathematics teaching and learning, one needs to broaden and deepen teachers' understanding of mathematical content, mathematics knowledge for teaching, how children think and learn about specific mathematical content, and how students come to develop and use mathematical representations for scientific and everyday phenomena. The goal of the project is not to give teachers ready-made lessons or curricula to use, but rather to prepare them to develop their own learning activities through better understanding of mathematics and of how students think and learn.

Three aspects guide our goals and analysis of teacher development and student success in learning:

- Use of algebra as a modeling tool in extra-mathematical contexts,
- Use of multiple representations for functions (natural language, tables, number lines, graphs, written notation), and
- Willingness to explore problems in depth, considering all potentially relevant aspects before proposing solution methods and answers.

After the implementation of the first course, the team decided that, in order to achieve optimal effectiveness, teachers should have the experience of bringing their new understandings and points of view to the classroom by (a) planning and implementing new learning activities related to the mathematical content they were studying; (b) documenting this implementation through audio, video, and collection of students' work; (c) reflecting on results of the implementation; (d) and receiving feedback from peers and course instructors based on their documentation at various stages in the process. This led us to include in each course unit, one week in which groups of two to five teachers design a learning activity based on the topic they have been exploring in that unit. By the end of the course, they will also individually implement and evaluate one of the designed activities in the classroom.

Project Design in Relation to Strand 2

Three cohorts, each made up of 60 teachers of mathematics in grades 5 to 9 from nine New England school districts, participate in three graduate-level online courses, jointly designed by mathematicians, physicists, and mathematics education researchers. They also participate in weekly discussion forums in their schools.

The three courses focus on (1) Representations, (2) Transformations, and (3) Invariance and Change. Course units involve three weeks of online work on written notes, video presentation by instructors, software demonstrations, examples of videotaped classroom lessons, and other materials. Currently, in the first week of each of the four course units, teachers explore the topic, discuss models of teaching the unit's specific subject, analyze students' ideas and challenges in learning the subject, and solve problems that are relevant to their learning and teaching. In the second week they are guided to develop a deeper understanding of the mathematical content of the unit, again through notes, videos, problem solving, and online discussions. The third week is dedicated to the development of the learning activities by groups of teachers and to preliminary classroom implementation and evaluation of these activities. For the final course project, each teacher implements and evaluates one activity in his/her classroom.

Lessons analyze the mathematics and science taught from grades 5 to 9 and present a research-based approach to the educational challenges associated with its teaching.

The content of the three courses are:

Course 1: Representations: Focuses on the real (number) line and coordinate systems for representing mathematical objects (real numbers and relations, including functions) and for modeling relations among quantities. The primary goal is exploring and increasing the understanding of algebraic and geometric representations in these systems. Teachers discuss selected examples from educational research to gain insight into students' reasoning about number lines, coordinate systems, and the mathematical objects they represent. They discuss models of rational numbers as well as models of relations among physical quantities.

Course 2: Transformations: Takes a deeper look at the number line, especially the relation between fractions and rational numbers and divisibility and factorization. Transformations of the line and the plane are used to describe the arithmetic operation, to understand algebraic and geometric representations of functions and the solution of equation, and to introduce classification and the study of geometry. Particular attention is paid to transformations among physical quantities (such as distance and time). Research about middle-school children's approaches to transformations are examined in light of the distinction between input-output and differential approaches to functions that are congenial to closed-form and recursive descriptions, respectively.

Course 3: Change: Deals with various aspects of change, from the effects of change on equations and inequalities, comparison of different types of functions for representing change, to the meaning of rate of change. Studies of students' understanding of various kinds of change over time (e.g. in displacement, height, wages) and their interpretation of graphs are considered.

Section 3: Explanatory Framework

The first course was offered in the Spring of 2011 and systematic data about its impact is being collected and analyzed. To date, the success of the first course can be evaluated by our teacher retention rate by the middle of course 2 (92%) and their enthusiastic feedback and suggestions on course activities. There is also a substantial amount of anecdotal evidence that they think more deeply about several of the concepts they teach, understand better the connections among different topics, and are beginning to value the role of initial exploration of particular examples, and the role of conjecture and proof.

The impact of the Poincaré Institute's activities will be analyzed in terms of: (a) teachers' implementation of effective teaching activities and of (b) teachers' and (c) students' evolving understanding of mathematical content and representations.

(a) Teachers' implementation of effective teaching activities aims at detecting specific shifts in their ways of teaching, through the analysis of videotaped lessons collected at the start and at the end of each course and through the analysis of their week 3 submissions of plans for learning activities and later implementation of these activities. Here we also focus on the ways in which they begin to focus on understanding more than procedures, attend to student reasoning and ways in which to create bridges between mathematical understandings and student reasoning. In addition to identifying the shifts, we will also look in detail at the individual trajectories of teachers, detailing possible juncture points in their shifts and possible causes for these shifts. For instance, were the shifts due to course content, course instructors' feedback, in-district group discussions, or a combination of these factors?

(b) Data on teachers' and students' evolving understanding of mathematical content and representations are being collected through written assessments designed by the project team (for both teachers and students), state-mandated assessment results (for students), teachers' weekly submissions in each of the online courses, and samples of teachers' video-taped lessons. Data for the students were collected at the beginning and end of the first school year in which the project has been implemented (Fall 2011 and Spring 2012 as a pre and post baseline), as well as at the end of the project's five-year duration. For teachers in each cohort, data are collected at the start and end of each three-course sequence. This will allow analysis of overall progress and of progress related to participation in online courses.

Section 4: Lessons Learned

The Poincaré team is composed of mathematicians, physicists and education researchers that came to the project with different experiences and expectations. After the completion of the first course, the team is better aware of the topics that teachers are more interested in and how to present them to stimulate discussion. We also discovered that the integration of the mathematical content with the design of classroom activities increased the interest of the teachers in both. We identified a number of effective teachers and others whose lessons could be easily improved through feedback and discussion with course instructors and with their peers. We also noticed that most teachers are eager to adapt and incorporate new teaching methods when they are taken from an actual classroom and presented to them through either videos or student assignment.

Assessment and classroom video data on the impact of the project on teachers and students' learning will only be available by the end of 2012. For now, we have found that the learning activities teachers have developed during the third week of each of the four units in Course 3 are very informative in terms of how they propose to use content and teaching approaches inspired by their participation in the project. During the MSP-

LNC Conference we will present the results of the systematic data analysis we are now conducting on these learning activity proposals. Our analysis focuses on changes over time regarding four major themes, with related subthemes:

(a) *Content:* Focus and depth of mathematical content; Concepts presented in a way that allows students to understand more advanced concepts later in the syllabus or in other grades; Connections with previous topics and building on previous knowledge; Consideration of relevant aspects of the topic; Use of algebra and functions as a tools to solve problems.

(b) *Lesson Design*: Statement of lesson goals; Balance between use of large group, small group, and individual discussion and instruction; Nature of the questions, examples, and problems the teacher chooses; Design of situations in which children are able to reflect on the nature and structure of the problems; Use of multiple representations; Types of evaluation and assessment of student understanding; Consideration of applicability of lesson in other contexts;

(c) *Students:* Focus on student thinking; Focus on opportunities for students to construct conjectures and justifications; Anticipation of students' resources and difficulties; and

(d) *Teacher Moves:* Nature of teacher's responses and questions to address students' strategies, difficulties, and questions.

Abstract Title:
Using Teacher Liaisons to Support and Promote Effective Algebra Teaching

MSP Project Name:
NebraskaMATH

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Strand 2

Summary:
NebraskaMATH is a 5-year Targeted Math Science Partnership Project, whose goal is to improve achievement in mathematics for all students and to narrow achievement gaps of at-risk populations. Nebraska Algebra is the component of NebraskaMATH which targets Algebra 1 teachers in order to support them in becoming more effective Algebra 1 teachers. Participants take three graduate courses focused on increasing their knowledge of algebra, of cognition and motivation, and of pedagogy; we believe these areas are crucial to helping teachers teach algebra more effectively. During the academic year, participants are matched with a teacher liaison to help support them as they transfer knowledge gained in their courses into classroom practice, thereby improving instruction and increasing student achievement in algebra.

Section 1: Questions for dialogue at the MSP LNC

How can we best support more effective teaching in algebra 1?

How can we best support high school mathematics teachers to change their practices to become more effective when the teachers are spread out across a very large state?

How can teacher leaders best help teachers become more effective mathematics teachers, while minimizing costs and time out-of-classroom for the teacher leaders?

Section 2: Conceptual framework

NebraskaMATH is a 5-year Targeted Math Science Partnership Project, whose goal is to improve achievement in mathematics for all students and to narrow achievement gaps of at-risk populations. NebraskaMATH also puts high priority on developing sustainable statewide partnerships. One of the main programs of NebraskaMATH is Nebraska Algebra, which targets

Algebra 1 teachers. NebraskaMATH focuses on key transition points: induction for new teachers (New Teacher Network), giving students a strong foundation K-3 (Primarily Math), and helping students transition to abstract thinking in algebra (Nebraska Algebra).

We see effective teaching in algebra as utilizing the Standards for Mathematical Practice from the Common Core State Standards, and orchestrating instruction to maximize student learning. We believe teachers need to have a strong knowledge of mathematical content, of students and how they learn, and of pedagogy in order to be effective. Thus, Nebraska Algebra includes three graduate courses to address these components: Algebra for Algebra Teachers, Cognition and Instruction for High School Algebra Teachers, and Field Studies in Mathematics Education, courses which focus on the mathematics, the students, and the pedagogy, respectively. The first two courses are paired during the summer, while the third course is held across the ensuing academic year. During the academic year, participants are provided with both a mentor (a member of the instructional team) and a liaison (a master teacher who plays a mentoring-type role). In the districts large enough to employ mathematics coaches, we encourage the districts to focus some of the coach's efforts on the Nebraska Algebra participants.

Algebra for Algebra Teachers focuses on high school algebra topics from an advanced standpoint (this is essentially a modern algebra course focused on drawing connections to high school algebra). Cognition and Instruction for High School Algebra Teachers focuses on topics in cognition and motivation related to teaching adolescents mathematics. Field Studies in Mathematics Education focuses on helping teachers implement knowledge gained in the two summer courses into their classroom practice during the ensuing academic year. This discussion will primarily address issues surrounding the third course, TEAC 991 Field Studies in Mathematics Education, in which implementing changes in classroom practice is directly addressed.

We see the teacher liaisons as a cost-effective way to support participants as they work to become more effective algebra teachers. A teacher liaison is a colleague who has previously completed the Nebraska Algebra program that is matched with approximately five current teacher participants with the primary responsibility of helping the teacher participants be more reflective in their work. After being matched with their group (and meeting them during the summer institute), the teacher liaison performs the following functions during the subsequent academic year:

- serve as small group facilitator during the face-to-face workshops which open and close the academic year course (which convenes online in the interim);
- maintain regular email communication with the teachers enrolled in the course;
- provide feedback on weekly reflections submitted by the teacher participants as part of their course requirements using NebraskaMATH's online networking platform; and
- communicate with course instructors as needed to support the instruction of the course.

The liaison/teacher-participant relationship is a power free, two-way mutually beneficial relationship through which knowledge, experiences and camaraderie are shared.

Section 3: Explanatory framework.
While Nebraska Algebra does not have a formal research component, evaluations reveal that participants find the program very valuable. Participants, especially those who initially believe they have no need to learn additional mathematics, find the sequence of Nebraska Algebra courses to be very beneficial. The evaluation plan surveys the participants before and after participation in Nebraska Algebra, and then reports to NebraskaMATH leadership, in order for the evaluation results to inform future iterations of courses and other NebraskaMATH work.

During early iterations of Nebraska Algebra, although much of its activity took place during the academic year, the mentoring component of the program was viewed as separate from TEAC 991, the academic year course. In this way, participants in other programs within NebraskaMATH that were not enrolled in TEAC 991 could also benefit from collaboration with a mentor. We originally planned to assign each participant two mentors—one from the university and one K-12 teacher leader. The K-12 teachers enlisted to serve as mentors were coordinated by the NebraskaMATH program manager. Mentors were provided with suggestions on how to initiate contact with teachers and develop a working relationship, and were provided with a “menu” of ways in which teachers and mentors might structure their time together.

Informal feedback from mentors and teachers revealed that since many participants in Nebraska Algebra were experienced, veteran teachers the utilization of the term “mentor” was problematic both on the part of the teacher participant, and on the part of the teacher serving as the mentor. In addition, teachers serving as mentors found it difficult to initiate meaningful interactions (and therefore relationships) with the teachers without a prescribed structure for their interaction. Furthermore, since the time spent collaborating with a mentor was not directly connected with TEAC 991 course goals, what was intended to be a means of providing support for teachers enrolled in the course was sometimes perceived as time spent fulfilling additional course requirements.
Finally, other than the team of three TEAC 991 course instructors, the university mentors were not being utilized as the type of mentoring the participants needed during the academic year aligned much more closely to what the K-12 teacher leaders could provide. Consequently, the team of TEAC 991 instructors (who are themselves K-12 teacher leaders) were being stretched in the dual role of instructor and mentor, while the K-12 teachers enlisted as mentors were being underutilized. Yet end of course evaluations indicated that participants were seeking more, consistent interaction with instructors and colleagues, particularly as it related to course requirements of submitting weekly reflections about progress toward professional goals.

As a result, our mentoring program has evolved to the point that now we have it closely aligned with the academic year course and have replaced the word *mentor* with *teacher liaison*. Efforts to support teachers participating in Nebraska Algebra are structured around regular interactions with teacher liaisons and course instructors that are closely aligned with TEAC 991 course goals. While participants do use the summer instructional team IHE faculty and grad students as resources when they have content questions, they seem to primarily rely on their liaisons and TEAC 991 instructors for questions related to effective algebra instruction during the academic year.

As monitored by the course instructors, the consistency and quality of weekly reflections assigned during TEAC 991 is indicative of the positive impact this structural change has had on the success of the course.

Section 4: Lessons learned

As described above, the use of teacher liaisons to support effective algebra teaching is an idea that has evolved across the life of Nebraska Algebra. We have found that the type of mentoring the participants need when implementing changes in classroom practice aligns much more closely to what teacher leaders can provide. We also know that interactions between teacher liaisons and participants that are structured around specific tasks related to the academic year course goals results in greater growth toward achieving those goals. Since the course goals are aligned with participants' professional goals, the result is more effective STEM instruction.

Another lesson learned relates to having the three courses be strongly connected to each other. While we still believe that, in theory, the more interconnected the three courses, the better, we have found that in practice, this interconnection is harder to achieve than we would like. It takes great effort on the part of the instructors to bridge the existing communication gaps among departments and IHE/K12 and to develop relationships deep enough to support conversations about changing courses to better connect to each other. If the relationships are not deep enough, some instructors will resist making changes, and remain unconvinced of the potential value of providing participants with a fully integrated experience across three courses. Additionally, as the makeup of instructional teams change over time, there is a constant need to attend to the relationships among instructors, if we are to provide participants with as rich an experience as possible.

We have also learned that it is hard to get teachers to focus on instruction: it is much easier to talk (complain) about students, school structures, and NCLB-related assessments. However, when instructors clearly communicate high expectations for participants to focus on their own instruction, we can see change. This focus needs to be very intentional on the part of the instructors, and cannot be assumed.

The academic year instructional team is in regular contact with all of the participants. These conversations help to shape the supports provided to participants during the year, as well as shape the entire Nebraska Algebra program for the next group of participants. We believe that the ability of instructors to listen to participants is the key component to constantly improving Nebraska Algebra to better support more effective algebra teaching.

Abstract Title:
Aligning university professional development with the K-12 educational context to support effective teaching

MSP Project Name:
Project MAST

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Strand 2

Summary:
Effective post-secondary STEM teaching relates the material being taught with teachers' prior knowledge and experiences, and helps them apply what they're learning to their classroom context. The Mississippi Academy for Science Teaching's (Project MAST) staff and external evaluators closely monitor the alignment of university professional development with K-12 policies and practices through observations, instructor interviews, teacher surveys and school site visits. This session describes Project MAST's efforts to support STEM instruction by improving the teaching done by STEM faculty, adjusting the content of the professional development, and educating school administrators about the ways in which they can best support their teachers. This session shares our evidence-based reflective process and the lessons learned along the way.

<u>Section 1: Questions for dialogue at the MSP LNC</u>

How does the K-12 educational context mitigate teachers' ability to apply what they've learned in university professional development?

What are the potential discrepancies between the STEM professional development that teachers receive in a university setting and the practices and policies in K-12 schools and districts?

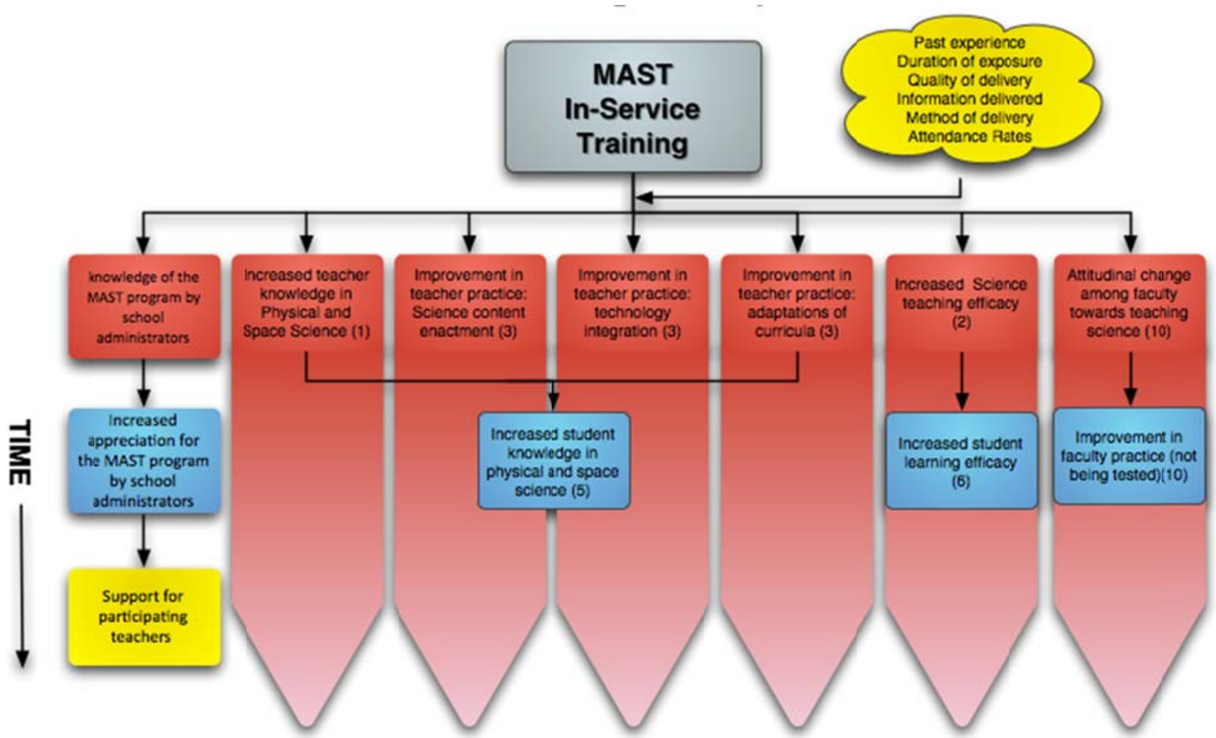
What are some strategies for aligning professional development with the K-12 context? How can all stakeholders (e.g., university faculty members, PD program coordinators, teachers, and school administrators) work together to support effective STEM teaching?

Section 2: Conceptual framework

Effective STEM teaching bridges content and context; it relates the material being taught with participants' prior knowledge and experiences, and helps learners apply knowledge and skills to new situations. Preparing STEM teachers and faculty to teach effectively therefore requires continued awareness of the backgrounds and working conditions of K-12 teachers and the alignment of professional development to classroom practice. Over the last three years, the Mississippi Academy for Science Teaching (Project MAST) has been documenting the coherence of its university-based activities with K-12 practices and policies and adjusting its programming to better support effective teaching. We have been especially interested in improving our collaborations with university faculty and school administrators to ensure that what faculty teach in their professional development is consistent with what teachers normally do in the classroom, and that administrators give teachers ample opportunities to practice and reflect on what they've learned. This session shares our evidence-based reflective process, and the lessons we've learned along the way.

Project MAST, a five-year Targeted MSP at Jackson State University, prepares teachers from under-performing high schools in Mississippi to teach Physics, Chemistry, Earth/Space Science and Physical Science. During four weeks of graduate coursework (three weeks in the summer, five Saturdays during the school year) teachers learn physical science content and pedagogy through lectures and high school-appropriate hands-on activities. Teachers learn from JSU faculty and world-class instructors from other universities, businesses, school districts and federal agencies, and receive approximately $2000 worth of instructional materials to use in their classrooms. During the school year, teachers also receive three visits from Project MAST to either observe and support teaching, or bring instructional technologies (a portable planetarium, iPods with science podcasts) to the classrooms. The combination of graduate courses, instructional materials and classroom visits is expected to lead to improvements in teachers' content knowledge and teaching efficacy, and ultimately to growth in student content knowledge and positive attitudes toward science (Figure 1).

Figure 1. MAST Theory of Change



Project MAST incorporates five critical features of professional development for effective teaching: “(a) content focus, (b) active learning, (c) coherence, (d) duration, and (e) collective participation” (Desimone, 2009, p 183). By design, teachers receive an ample amount of PD that uses hands-on activities to teach science content and pedagogy. Teachers within the same school are encouraged to apply to the program, thus facilitating collective participation and resource sharing. The truest test of a PD program’s effectiveness, however, is how well teachers can use what they’ve learned in their classrooms. To do that, PD must be consistent with teachers’ knowledge and beliefs, as well as with school, district and state policies and standards (Desimone, 2009; Penuel, Fishman, Yamaguchi & Gallagher, 2007).

MAST staff and external evaluators have collected data from multiple sources to monitor and improve PD coherence. First, trained faculty members observed all PD sessions using a structured protocol. One of the constructs they observed is whether instructors make explicit connections to participants’ prior knowledge and past PD experiences, or to the Mississippi 9-12 standards and educational context. Second, external evaluators interviewed a sample of PD instructors, asking them among other things if there was any information they wish they had been given about the participants while planning their session. Third, in post-program surveys, teachers rated the consistency of the PD with their own goals, with their past PD experiences, and with their school or district’s plan to change practice (items taken from the national evaluation of the Eisenhower Professional Development Program, U. S. Department of Education, 1999). Finally, MAST staff members visited the classrooms of all participating teachers, and conducted extended site visits with a sample of teachers to create case studies of PD implementation. The site visits consisted of interviews with each participant, school administrators or science department chairs and student focus groups, and classroom observations of the relevant physics, chemistry, earth or physical science courses taught by each participant (Cooper, Bass, Mushlin & Fadavi, 2011).

Section 3: Explanatory framework

Data from two years of Project MAST implementation suggest that while project activities are generally consistent with teachers' background, goals and instructional context, there is room for improvement. Not only can the university faculty members better relate their PD sessions to their participants, but school administrators can do more to support their teachers' implementation of MAST activities and teaching strategies. Project MAST program coordinators can also continue to fine tune how it provides both groups with the information and support they need to accomplish these goals.

Advice for and from university faculty
Observations indicated that in the majority of PD sessions each year (61.5% in year 1, 88.9% in year 2), instructors made connections to participants' prior knowledge or experiences. For instance, during a stochiometry workshop the observer noted,

> *In general, in addition to asking the whole class about their common experiences, the instructor asked individual participants for additional information. Specific examples of each: At the outset the instructor wanted to know about the participants, their teaching experiences and the number of students in their classes.*

Less than half of the workshops explicitly related the material instructors were teaching to the local K-12 educational context (e.g., the state's Science Framework or teachers' access to technology resources). In at least one instance, an instructor from outside the state planned to introduce a lesson in which high school students would work on individual computers, only to learn that many teachers had their own computers but lacked easy access to computer labs. The instructor had to reshape the session on the spur of the moment to show how the lesson could be taught as a teacher demonstration rather than a student-driven hands-on activity.

In follow-up interviews, PD instructors noted that while they generally felt prepared to teach their assigned content to the Project MAST audience, some would have liked to have known more about teachers' expectations for the workshops and their motivation for being part of the program:

> *I felt like I had enough information on the content. I think that I would have liked more information about the audience in terms of the range of the teachers' experience and maybe the teachers - both maybe the overall MAST and the teachers', expectation of what they would like to have from the workshop. I didn't really have anything like that; something about is the emphasis, where the emphasis on the material should be. I think I would have appreciated more information that way.*

Understanding administrator support
After the professional development, Project MAST staff members visited teachers' classrooms to observe the implementation of MAST activities. Case studies of four teachers suggested that participation in Project MAST had led to increased confidence and greater sense of community with other teachers throughout the state. While teachers gained colleagues with whom they could

share resources, they often wanted more local support for their work, especially from their school administrators (Cooper et al, 2011).

Ideally, administrators could help teachers in a number of ways, from authorizing the purchase of science materials to offering instructional support (e.g., through feedback on pedagogy or establishing professional communities of practice for teachers to share what they've learned). The cases indicated that administrators are not an impediment to the implementation of MAST activities and strategies in the classroom, but they are not doing all that teachers believe they can to support MAST in schools. They view Project MAST favorably because they see the increased confidence in their teachers and are glad to receive the additional lab equipment and instructional resources. Administrators are willing to support MAST teachers by improving material conditions in science classrooms: purchasing new chemicals, purchasing a classroom set of Vernier LabQuests, funding a new computer lab. However, they are not providing instructional leadership to change science pedagogy. Two administrators seemed intimidated by the science instruction they saw, one saying that his teachers were doing work that he had not done until he was an undergraduate. Another, a former biology teacher, remarked that he could not provide his MAST participant teacher with much feedback on her teaching because it was so different from the way he had taught it two decades prior. Knowledge of and appreciation for MAST are resulting in some kinds of support, but not others.

Administrators can also support their MAST teachers by assigning them to teach physical science in the fall after their summer professional development. While this is one of the requirements for participation, several teachers each year are dropped from the program because they have been assigned to teach biology, mathematics, or other subjects between the time they started Project MAST in the summer and the time they returned to their classrooms that fall. Project MAST staff members believe strongly that teachers must have the opportunity to immediately practice what they've learned and receive feedback. If administrators do not allow teachers to teach the classes on which they've just been trained, then the knowledge and skills they've gained becomes stagnant and limited in its effectiveness.

Section 4: Lessons learned

Since writing our NSF proposal, we've become increasingly aware that all professional development – like politics – is local, and that large-scale, statewide professional development initiatives must be cognizant of school and teacher-specific contexts and challenges if their programs are to be truly successful. Aligning PD content to school contexts requires viewing our program from a learner's perspective, incorporating feedback from our university faculty, participating teachers, and their school administrators, and facilitating collaboration between program stakeholders. The alignment process requires faculty to adjust their PD to match teachers' backgrounds and experiences, but that alone will not produce effective teaching. School administrators must also be prepared to support participating teachers to successfully apply what they've learned in the PD, and the professional development program itself must be responsive to what it learns with each cohort of participants.

Our evaluations have led us to give more information to PD faculty instructors about teachers' background and access to technology. Before this summer's Project MAST sessions, we surveyed incoming teachers about their technology access and skills, sharing the results with PD instructors. We also included more opportunities in the summer workshops for teachers to discuss how they would apply or adapt what they were learning to their upcoming courses. These conversations gave faculty instructors greater insight on teachers' educational context and helped them tailor their advice and instruction to teachers' needs. We also had teachers blog during the summer workshops using Tumblr, a free, short form blogging client. We're in the process of analyzing the summer blogging and developing prompts for the spring workshop sessions. We hope to use the blogs to gain a snapshot of our participants' engagement "in the moment," during the intense, three-week summer workshop. In addition, we are developing a structured way to provide our participants with collaborative unit planning opportunities at the end of the summer workshops so that they can spend some time "localizing" the professional development experiences and classroom resources they've received.

We've also been strengthening our outreach to school administrators to help them develop the awareness, knowledge, skills and confidence needed to help teachers make the most of their Project MAST experience. We have been meeting annually with an advisory board of teachers and administrators to monitor and improve the program. We also conduct a day-long seminar for administrators every February to introduce them to Project MAST and encourage them to recruit teacher participants. Administrators learn science through hands-on activities, hear testimonials from Project MAST graduates and receive information from the program directors to familiarize them with MAST requirements and benefits. The seminars also include talks and activities by guest speakers (usually university faculty with national reputations in science education) on science learning or school reform.

Participants complete a survey at the end of the seminar about their satisfaction with their experience and their understanding of MAST's goals and activities. Results from the 2011 seminar survey were mixed. On the one hand, participants seemed to have a good grasp of the goals of MAST, with responses focusing on preparation, effectiveness, and professional development for science teachers. Respondents generally had a very high opinion of MAST, agreeing or strongly agreeing with statements like 'There is a need for a program like MAST in my school/district" (88% agreement). At the same time, there remained considerable confusion over whether participants must be teaching a MAST subject during the year they are enrolled in the MAST program. Three quarters of the respondents incorrectly believed that MAST was open to teachers who weren't teaching physical science.

The 2012 seminar will therefore aim to correct the misconceptions about MAST and give administrators specific, concrete suggestions for supporting their MAST teachers. Staff members and current MAST teachers will lead small group discussions with participants to explore teacher needs and brainstorm solutions. This exercise will also serve as another opportunity for our program to learn more about the gaps between our expectations of the support MAST participants receive and the support their administrators actually provide.

We hope that administrators will leave with an action plan containing ideas they can implement immediately and over the long term. We also hope that administrators will understand why

MAST teachers are required to teach physical science to participate in the program so that administrators will do everything in their power to schedule teachers appropriately.

All told, our MSP project experiences and the discussions we hope they foster have implications for making large-scale professional development sensitive to local contexts, and for establishing school or district practices that optimize effective teaching in classrooms.

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Abstract Title:
Supporting Freshman Physics Teachers

MSP Project Name: A TIME for Physics First in Missouri

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Strand 2

Summary:
Our project, currently in its third year, seeks to increase both the teaching effectiveness and leadership capacity of ninth grade physics teachers. Our professional development program, which consists of three summers of content-rich academies (10 weeks) and three academic years of online leadership courses, provides opportunities for teachers to strengthen their content knowledge, develop their use of modeling pedagogy, and expand their knowledge and skills for serving as leaders and catalysts for changes within their schools and districts. Through implementation of two different models, one that utilizes coaching (face to face classroom support) and one that utilizes mentoring (online support), we hope to understand how teachers can best be supported in enhancing their teaching effectiveness and impacting student learning.

<u>Section 1: Questions for Dialogue at the MSP LNC</u>
Our project, which is in its third year, has been working with teachers since Fall 2010. Our districts represent a wide variety – urban, suburban and rural. Some districts have large numbers of students, with a 10-20 9th grade science teachers. Other districts have a lone 9th grade science teacher. Additionally, we have a diverse group of teachers, whose experience in the classroom ranges from as little as one year to over 18 years. Our challenge is to provide appropriate support to all our participants, to enhance the effectiveness of their teaching and to develop their leadership capacity. Questions for dialogue at the MPS LNC include:

- How do the professional development needs of teachers vary according to career stage and local context?
- How can professional development best be designed to provide individualized support to teachers in their greatest areas of need?
- What methods of support translate to real, measurable learning among their students?

Section 2: Conceptual Framework

In recent years, there is growing recognition that while subject matter is essential, subject matter alone is not sufficient to ensure effective teaching. Rather, there is a specialized type of knowledge that enables teachers to transform their disciplinary knowledge into forms that are accessible and attainable by students. Shulman (1987) first introduced this notion as pedagogical content knowledge (PCK). This includes knowledge of how particular subject matter topics, problems, and issues can be organized, represented, and adapted to the diverse interests and abilities of learners and presented for instruction. It represents the synthesis of teachers' knowledge of both subject matter and pedagogy.

Shulman's model has been elaborated upon and extended by other scholars. Grossman (1990) viewed PCK as being the *integration* of several knowledge bases including subject matter knowledge, general pedagogical knowledge, and contextual knowledge, and as being generated and developed through (a) observation of classes whether as a student or student teacher; (b) disciplinary education; (c) teacher education coursework; and (d) classroom teaching experience. Building on Grossman's work, Magnusson, Krajcik, and Borko (1999) proposed a *transformative* model of PCK that includes five interacting components: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum (goals & objectives/ curriculum and materials), (c) knowledge and beliefs about students' understanding of specific science topics (prerequisite knowledge and student misconceptions), (d) knowledge and beliefs about assessment in science (dimensions of science learning to assess and knowledge of methods of assessment), (e) knowledge and beliefs about instructional strategies for teaching science (topic-specific activities, e.g., activities for teaching photosynthesis; as well as subject-specific strategies, e.g., inquiry).

The assumption underlying our work is that teachers with well-developed and robust PCK will be better able to support their students' learning—that is, student outcomes and growth in student knowledge and skills are measurable outcomes of effective STEM teaching. In this sense, our definition of "effective teaching" from a research standpoint (well-developed PCK) is not incompatible with that of other stakeholders (teaching that results in higher student achievement).

Section 3: Explanatory Framework

A strong grasp of subject matter is necessary, but not sufficient for effective teaching. In our program, we recognize that individualized support is necessary for teachers to translate what they learn into their classroom practice and develop robust PCK. Coaching and mentoring are two forms of support that have empirical support. Recent work indicates that mentoring and coaching relationships may benefit from the use of technology. "Blended" or "hybrid" professional development models that couple both more traditional face-to-face activities with online interactions are becoming more increasingly common with the explosion of available technologies and platforms. In this project, we are interested in understanding the strengths and weaknesses of two different hybrid models in order to compare their relative effectiveness in supporting teachers in making a positive impact on student learning. Findings from this study will contribute to the knowledge base for design of effective hybrid professional development.

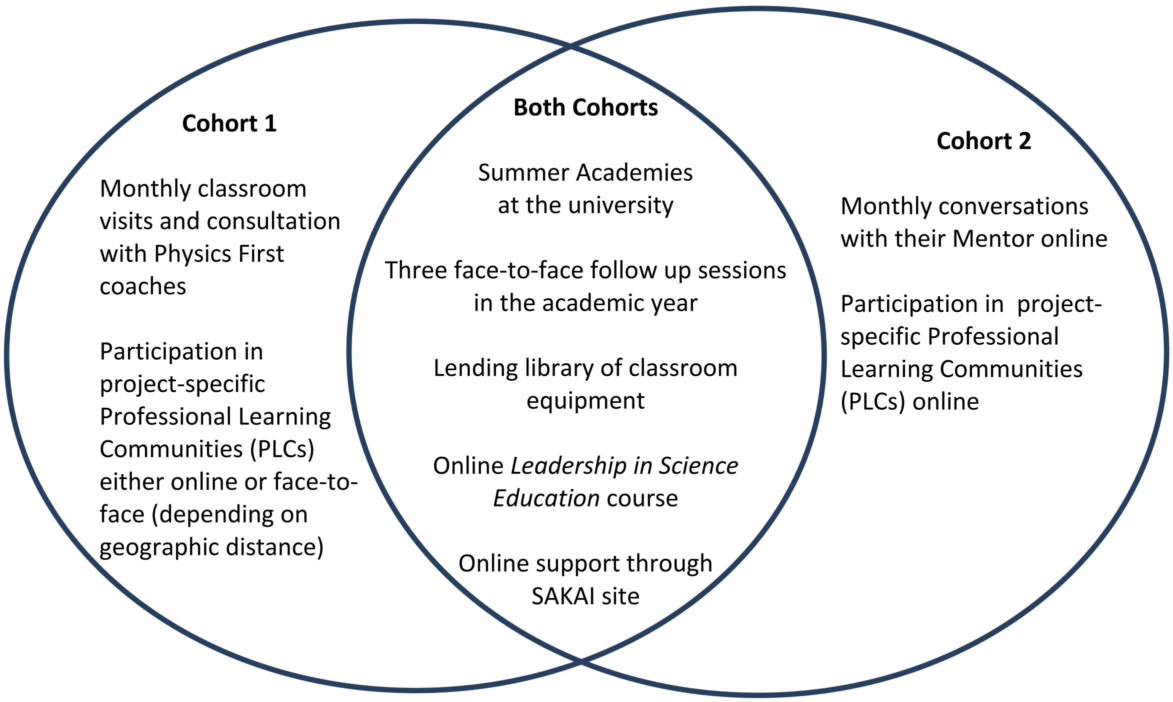

Figure 1. Comparison of Two Professional Development Models

We are implementing and comparing two professional development models; one of which utilizes face to face coaching and another which relies on online/virtual mentoring. Participating schools were randomly assigned to two cohorts, based on the building's standardized math test scores. The project used a delayed entry design, with the first cohort (C1) receiving face to face (F2F) coaching during the academic year, and the second cohort (C2) receiving online mentoring during the academic year. (Both cohorts participate for a total of three years). Figure 1 (above) highlights similarities and differences between the two models.

To examine how these models support effective teaching and, in turn, lead to improvements in student learning, we are examining several sources of data. These include:

- Pre/post measures of teachers' content knowledge
- Pre/post surveys of teachers' typical pedagogical practices
- Observation and reflection records related to interactions with coaches and mentors
- Pre/post measures of students' content knowledge
- Field notes from professional development sessions
- Electronic records of teachers' interactions online
- Surveys of teachers, students, and school districts

Analysis of this data over the long-term will allow us to compare and evaluate these two models in light of student achievement. Additionally, they will help us pinpoint the impact of specific components of the professional development on the different areas of teachers' PCK, such as their knowledge of assessment and instructional strategies.

Section 4: Lessons Learned

At this stage in our data collection and analysis, it would be premature to draw comparisons between the two professional development models and their effectiveness and impact on teachers (cohort 2 has completed less than 1 year of the professional development). However, as we have implemented the professional development program, we have become increasingly aware of the diverse ways in which teachers require support, and the role that we, as professional developers, can play in enhancing STEM teaching effectiveness. These fall into five broad categories:

1) **Support within local contexts –** the types of support teachers need are often idiosyncratic based on their local classroom, school, and district situations. Some situations benefit from support from academy instructors or peers, and others from district administrators. It has been important for the project staff to have active contact with district administrators, through a district liaison committee and though a two-day academy for administrators during the summer teacher academy.
2) **Peer support-** PCK is thought to be the knowledge that resides among a community of practitioners; teachers need opportunities to share their collective "wisdom of practice" and to develop their effectiveness by working together as colleagues. To this end, we have found that providing opportunities for teachers to engage in sharing knowledge within their cohorts is highly valued. At each follow-up session we allot time for "share-a-thons" in which teachers are individually scheduled to present and/or dialogue about their successes and challenges in implementing 9th grade physics.
3) **Online vs. Face-to-Face support from Mentors (online) and Coaches (F2F)** Ten coaches and mentors are part of the staff of the project. They attend summer academies with teachers, meet/communicate online with teachers on a monthly basis, attend Cognitive Coaching training, and communicate among the group and with a coach-mentor coordinator monthly. Coaches and Mentors are the project's eyes and ears in the field. Teachers have definite preferred ways of work and communicating; though available technologies may provide affordances to support their development, the degree to which these affordances are realized is dependent on teachers' willingness to adopt new technologies and forms of interaction. To this end, we have been monitoring and analyzing teachers' utilization of online tools (e.g., SAKAI) throughout the program in order to better understand how these can be leveraged in ways that best meet teachers' needs in terms of their knowledge of learners, curriculum, instruction, and assessment.
4) **Pedagogical Support-** Initially, we proposed that pedagogy be embedded within content instruction during the summer academy; however, we found this insufficient for teachers to develop a robust understanding of modeling pedagogy. Additionally, we found that our instructors (science faculty) also held tacit notions of this pedagogy. Subsequently, we have identified means for dialoguing with one another and making aspects of the pedagogy explicit within our own teaching (modeling appropriate pedagogy), as well as to engage teachers in reading the research literature on modeling instruction, analyzing how the curriculum supports this type of instruction, and exploring how modeling practices can effectively support student learning in science.
5) **Curricular Support-** We utilize a project-specific curriculum for 9th grade physics, which teachers are introduced to in the summer academy, then implement in their classrooms during the academic year. The content of the curriculum is specifically written by the Curriculum Revision Team (also the Teaching Team), and covers topics in Electricity, Uniform and

Accelerated Motion, Forces and Newton's Laws, Applications of Newton's Laws, Energy, Thermal Energy, Waves and Planetary Motion. The curriculum is written to be directly usable with students in the classroom, and is annotated with teacher notes, objective, misconceptions, big ideas and support material, and is consistent with inquiry and modeling pedagogies. One copy of all equipment needed to conduct labs is provided to each teacher.

We are in the process of identifying the types of curricular supports that are necessary for teachers to effectively support student learning; that is, we are attempting to produce *educative curriculum materials* that will support the development of teachers' PCK. "Educative curriculum materials should help to increase teachers' knowledge in specific instances of instructional decision making but also help them develop more general knowledge that they can apply flexibly in new situations" (Davis & Krajcik, 2005, p.3).

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Abstract Title:
Evoking the Core Mathematical Practices from Teachers

MSP Project Name:
New Jersey Partnership for Excellence in Middle School Mathematics (NJ-PEMSM)

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Strand 2

Summary:
This presentation describes the structure of an MSP Institute for mid-career middle school math teachers intended to deepen their understanding of the mathematics of the middle grades and of some key aspects of mathematical pedagogy. The mathematical practices called for in CCSSM are implicit in our basic definition of effective teaching and learning. We make explicit reference to these "core practices" in this presentation.

Section 1: Questions for dialogue at the MSP LNC
What are the obstacles that teachers face in reconsidering and deepening their understanding of the mathematics of the middle grades? What activities and interactions help teachers overcome those obstacles? To what extent do the "core mathematical practices" help teachers learn and teach with better outcomes? Can helping teachers use these "core practices" in their classroom instruction also help students internalize the values of these practices and use them to their own benefit?

Section 2: Conceptual framework
Effective teaching of the mathematics found in the middle grades (whether directed primarily toward mid-career teachers, prospective teachers, or school children) should have a number of characteristics. It is not clear that listing characteristics constitutes a definition in the sense a mathematician uses the word. None-the-less, here is an effort to list the most important characteristics as I see them.

1. The mathematical content should make sense. Since the middle grades are responsible for introducing many new concepts as well as new computational methods, it is important that the new concepts be elucidated by appeals to physical evidence, numerical evidence, and reasoned connections to prior mathematics. Learners should explore and discuss not only examples of objects that fit a new definition but also examples of objects that do not fit. A variety of physical models and kinesthetic explorations can be helpful. Alternation between the concrete and the abstract reinforces the benefits of both generalization and specialization.
2. Students (and teachers) need help to develop the intellectual stamina and the professional communication skills to persist in understanding math and applying it to analyze and solve

problems. Effective teaching will provide opportunity to build stamina and become fluent with asking and answering probing questions. Questioning allows learners to engage in critique of others' reasoning, to build coherent arguments of their own, and to acquire the habit of monitoring their own reasoning to note and correct errors. Effective instruction encourages teachers and learners to improve the precision of their mathematical work.

3. Teachers (including teachers of teachers) should make use of a wide variety of pedagogical methods and mathematical explanations and methods. No one method works all the time; even if it did, it would become boring and lose its effectiveness. Similar comments apply to selection of mathematical tools and strategies.

4. Since people learn most easily and remember best what makes sense, is credible for good reasons, and connects to prior knowledge – good teaching should emphasize building up from well chosen motivating examples to general statements, and should provide evidence and connections as it goes. Along these lines, effective teaching allows learners to recognize and/or formulate patterns of repeated reasoning and/or repeated structures in the mathematical content.

We believe that the CCSSM standards of mathematical practice apply not only to school children but also to teachers, mathematics educators, and instructional staff at post-secondary institutions. Indeed, these practices represent the core of mathematical practice in all sectors and all levels.

Each day's instruction includes exploratory exercises built into exposition, workshop sessions where teacher participants work collaboratively on problems with Institute staff as coaches, classroom connection sessions discussing how and why to translate content to the middle school classroom, and group presentations in which teachers explain their work using the ideas mentioned above. Thus, we model these aspects of good teaching – and encourage our participants to use them in their own learning and in their teaching.

Section 3: Explanatory framework

Cohort 1 of our Partnership Institute has completed its seven-course program. Its 25 members are beginning to take on formal and informal roles assisting their peers to understand more deeply the mathematics they teach. Cohort 2 (21 teachers) will have completed four courses by the time of the 2012 NLC. Cohort 3 (30 teachers) will have completed 2 weeks of their first semester-long course. Each course is supported by an instructional team and observed by a small research team. There is extensive video-recording of the summer institute courses for research and evaluation purposes. Our Partnership initially included 7 districts; it now has 15. Some districts have only one middle school; the largest has over 20.

The teacher participants report that the PEMSM Institute provides the most intense and valuable professional development they have experienced. In some cases, initially skeptical teachers have become vocally enthusiastic about the extended content-based courses. They like the opportunity to work in groups for extended periods of time on mathematically engaging problems that connect different parts of the middle school curriculum. They find that having time to converse with colleagues from their own schools and from schools in other partner districts is valuable. They enjoy the challenging yet accessible nature of the work we ask them to do. They like discovering that they can understand more when they have the time, the stimuli, and the support to do so.

The discussions at the Conference “Enacting Standards for Mathematical Practices” at the University of Nebraska-Lincoln in October 2011 provided stimulating ideas about the incorporation of these practices into effective instruction. We are currently digesting some of those ideas to see how to make use of them in improving our Institute format.

We relied, perhaps too much, on the doctrine that teachers teach as they were taught – believing that if we present an institute employing a variety of effective instructional practices then teachers would mimic them in their own classrooms. According to our District Liaisons, there is already evidence that PEMSM participating teachers are bringing some of the practices we used into their own classrooms. We hope that more systematic observations in the future will support these observations. We will further strengthen our “classroom connection” sessions (during the summer Institute) to help teachers incorporate the Core Practices into their instruction and nurture those practices in their students’ work.

We administer the Learning Mathematics for Teaching (LMT) assessments for Number Concepts and Operations and Geometry annually for a longitudinal measure of growth in content knowledge for teaching. LMT results show significant growth. Also, every course gives project-developed pre- and post-tests: math courses test for content; the courses on children’s mathematical reasoning, motivation, and affect test understanding of those issues. Results show significant teacher growth; they also inform our ongoing course revisions. For example, revisions are planned to ensure that each day’s algebra work is more accessible and relevant to the full range of our participating teachers – including special education teachers, teachers of grades 5 and 6, and teachers of Pre-Algebra and Algebra in grades 7 and 8.

<u>Section 4: Lessons learned</u>

1. The introduction of very rigid “pacing guides” discourages teachers whose students can’t keep up, while simultaneously making it harder for teachers to teach for understanding and connection along with computational skills.
2. Many math teachers in middle school have had very little explicit instruction in the math of the middle grades since they left the middle grades themselves. They are eager to repair the gaps in their preparation, especially if that can be done in classes that treat them as professionals.
3. Math teachers without preparation in the sciences and other areas where math is now applied can feel at a disadvantage in answering questions from students about what the middle grade curriculum is good for and in answering questions from parents about why explanation and justification and approximation are just as important as computational fluency in the traditional basic skills.
4. There is a fascinating intellectual challenge in figuring out how to present and explain mathematics to folks whose motivation lies in middle school teaching rather than in college learning or “real-world” application. My university faculty colleagues recognize this challenge, and appreciate the opportunity to work with math education folks who can help them understand the issues in designing a segment of exposition or a workshop problem that will really get at the underlying issues in ways that are mathematically accessible and correct.
5. With good workshop problems, teachers can get very deeply engaged in understanding the material, in finding multiple representations and multiple solution methods, and in explaining these results to their peers. They can surprise themselves as well as their IHE-based instructors.

Abstract Title: Mathematical Knowledge for Teaching as a Critical Element of Preservice Teacher Preparation

MSP Project Name: Milwaukee MSP

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Strand 2

Summary
An important element of preservice teacher preparation is developing a deep knowledge of mathematics content that is relevant to teaching. However, not all preservice teachers elect the same math coursework which leads to variations in content knowledge upon program completion. Our MSP developed four content courses for preservice elementary (Grades 1-8) teachers electing a mathematics minor. I
t stands to reason that these individuals would demonstrate stronger mathematics content knowledge at the conclusion of their preparation program. To answer this question, we compare the results of preservice teachers with mathematics minors to non-mathematics minors on measures of mathematical knowledge for teaching (MKT) completed at the beginning and end of their programs.

Section 1: Questions for Dialogue at the MSP LNC

The main issues for discussion are the mathematical preparation of elementary teachers and ways to measure the extent to which these preservice teachers are learning the content necessary for effective STEM teaching. To promote dialogue, we will discuss the following questions in light of the results from a longitudinal study of the mathematical knowledge for teaching of preservice teachers throughout their teacher preparation program.

Does the mathematical preparation of preservice elementary teachers impact their mathematical knowledge for teaching?

What mathematics courses should be required of preservice elementary teachers electing a minor in mathematics?

What differences exist in the content knowledge of preservice teachers electing a mathematics minor compared with other preservice teachers?

Section 2: Conceptual Framework

At the core of effective STEM teaching in the area of mathematics is deep knowledge of the content that is relevant to teaching and the habits of mathematical practice. Effective teachers are well-aware of mathematical progressions and of the coherence of mathematics. Teachers with deep content knowledge can successfully help students understand complex ideas and make mathematical connections and applications, and help students develop mathematical proficiency. Content knowledge development begins in preservice teacher preparation with rigorous coursework aimed at ensuring that new teachers have the knowledge and skills needed to effectively begin their careers teaching mathematics.

The Milwaukee Mathematics Partnership (MMP), as one of its core initiatives, redesigned the mathematical preparation of teachers at the University of Wisconsin-Milwaukee. This work was based on recommendations highlighted in *The Mathematical Education of Teachers* (hereafter, MET) (CBMS, 2001) and *Adding It Up* (NRC, 2001). A vital aspect of our approach is the use of design teams comprised of a mathematician who is responsible for ensuring the course contains rigorous and correct mathematics; a mathematics educator who ensures the course aligns with current educational thinking and mathematics curricula; and a Teacher-in-Residence, who ensures course material relates to classroom practice. To that end, we revised the foundational mathematics content courses required of all prospective elementary and early childhood preservice teachers. Then we developed four new mathematics courses for preservice elementary teachers: (1) Mathematical Problem Solving, (2) Geometry, (3) Discrete Probability and Statistics, and (4) Algebraic Structures.

The development of the four new mathematics courses was of particular importance given that the university had just taken an extraordinary step to *require all elementary education majors to choose a minor in mathematics or science*, along with a second minor in social studies or English/language arts. In the past, when only one minor was required, most majors chose social studies and less than 8% chose mathematics. While the minor requirement had changed, the curriculum had not and education majors at first just elected from the existing array of mathematics courses. Thus, a goal of the MMP was to develop new courses specifically for the minor that built and deepened the content knowledge needed to teach mathematics in alignment with the MET and NRC recommendations and the findings of Ma (1999) and Ball and colleagues (Ball, 2003; Ball & Bass, 2003; Ball, Thames, & Phelps, (2008; Hill, Rowan, & Ball 2005). The 18-credit mathematics minor is in addition to two foundational mathematics courses for a total of 24 credits in mathematics content, in addition to six credits of mathematics methods. The minor also includes existing coursework in calculus concepts. The four new courses are now permanent course offerings as part of the elementary education mathematics minor. The central question of interest is whether or not preservice teachers enrolled in these courses have, in fact, developed deep mathematics content knowledge necessary for effectively beginning their careers as STEM teachers.

Section 3: Explanatory Framework

To study the impact on preservice teachers' mathematical knowledge for teaching (MKT), we are using measures from the Learning Mathematics for Teaching (LMT) project at The University of Michigan (Hill, Ball, & Schilling, 2008; Hill, Sleep, Lewis, & Ball, 2007). These items estimate ability in using mathematical knowledge in the context of teaching. The measures utilize item-response-theory (IRT) to evaluate items, construct scales, and report results. We construct our own scales from the bank of items and analyze the data using a two-parameter model.

In our longitudinal study, we track math course enrollment and measure the MKT of preservice elementary teachers at three time points as they progress through their teacher education program. The first MKT provides a baseline at the start of their mathematical foundation courses. The second MKT is measured after completion of the foundation courses and, most if not all, of the courses for the mathematics minor, but prior to taking the mathematics methods courses. The third MKT is completed at the conclusion of the mathematical methods courses. We are then able to compare the MKT of the elementary education major with a mathematics minor to those without a math minor. We hypothesize that teachers electing a mathematics minor and who take the new mathematics content courses will demonstrate stronger MKT than those not electing the minor. This comparison group design allows us to test this hypothesis with the goal of determining the effectiveness of the new content courses for deepening mathematical knowledge for teaching. In addition, we also track and measure the MKT of our early childhood majors as an additional comparison group.

We have been tracking preservice teachers and gathering MKT results for about seven years through our MSP. We now have a database of approximately 2000 preservice teachers who are either active in the teacher education program, completed the program, or have some other status. Overall, preservice teachers are demonstrating gains in mathematical knowledge for teaching as measured by the MKT assessments administered throughout their program of study. Results indicated that preservice teachers with a math minor have stronger MKT scores than those who did not elect a math minor.

The elementary teachers with a math minor began and ended their program with higher MKT scores than the non-math elementary teachers, the early childhood teachers, and the other category in all measures (i.e., Number and Operations, Algebra, and Geometry). These results may be due to self-selection bias where individuals who are more successful in mathematics, generally, score better on the MKT assessments and then self-select a math minor. An alternative explanation is that the additional math content courses taken by those electing a mathematics minor may explain the greater gains exhibited by these students.

We are in the process of compiling the results from 2010-2011 and adding it to the database. This will allow us to identify additional preservice teachers that have completed their program of studies and strengthen our analyses to test the hypothesis that taking additional math content courses is positively related to greater MKT. Repeated measures analysis of variance will also be conducted to determine if gains made throughout a preservice teacher's program are statistically significant and if there are any differential impacts given the program of study. In addition, we will conduct further analyses on the relationship of specific course enrollment to MKT. For example, do students who have taken the geometry math minor content course demonstrate greater geometry MKT gains than students who have not taken this course? Our intent is to further examined the data to gain a better understanding of the overall impact of the mathematical teacher preparation on preservice teacher MKT and provide direction and insights to further strengthen our program.

Section 4: Lessons Learned

We are now more convinced that prospective elementary teachers should enroll in mathematics content courses that are developed specifically for their program of studies so that they can study more deeply the mathematics content that they will be expected to teach. Our data shows that prospective teachers do grow in their mathematical knowledge for teaching throughout their teacher preparation program. However, do they learn enough content and learn it deeply enough to be effective STEM teachers? This presents an opportunity to follow some of these individuals into their teaching careers and more closely study their teaching practice and impact on student learning. Also concerning is that our early childhood preservice teachers generally have lower MKT scores than our elementary preservice teachers, even those without a mathematics minor. We are concerned that children begin their study of mathematics with teachers that have the weakest content knowledge. One response would be to require the early childhood preservice teachers to take another course to be comparable in preparation to elementary teachers or another potential site for deepening knowledge would be to engage them in sustained mathematics field work with young children.

We currently require two foundational mathematics content courses of all prospective elementary and early childhood teachers. The first course focuses on number and operations and the second on geometry, measurement, statistics, and probability. This just seems to be too much content for the second course and we wonder whether there should be a third foundational course.

We developed four mathematics content courses specifically for the elementary teacher mathematics minor. The resounding success has been the course on mathematical problem solving. This course is closely aligned with the expectations of the Standards for Mathematical Practice in the Common Core State Standards. The course engages preservice teachers in the habits of mathematical practice, and seems to shift their views on what it means to do mathematics and on their own abilities to investigate mathematics problems. The course on geometry also seems to be fairly successful. We have rearranged some of the content in this course and placed greater emphasis on some topics over others. However, the verdict is still out on the other two new courses, particularly the course on algebraic structures. We wonder whether these the right courses for the mathematics minor. We wonder whether the content in these courses is relevant to teaching elementary and middle school. We wonder if there topics or domains that we are missing.

Finally, given the release of the *Common Core State Standards for Mathematics*, we feel it is time to re-examine the courses, the content within each course, and the delivery of that content. The Common Core promotes focus on fewer topics with stronger knowledge of mathematical coherence, progressions, connections, and applications. It also emphasizes strong emphasis on specific visual models, such as the number line and area model. The Common Core is also very explicit in regards to the Standards for Mathematical Practice. While we have made progress in developing courses targeted to the preparation of elementary teachers, we also know we have more work ahead of us to ensure that our prospective teachers deeply know the mathematics articulated in the Common Core in order to strengthen their effectiveness as STEM teachers.

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Abstract Title:
Reconceiving "Misconceptions" in Teacher Professional Development

MSP Project Name: Minority Student Pipeline MSP

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Strand 2

Summary:
When science teachers engage in inquiry as part of professional development, facilitators often nudge them away from common misconceptions as quickly as possible, in order to help the teachers engage in more productive ways of thinking about the targeted concept. We argue that confronting certain misconceptions too soon can sometimes (often?) cut off productive lines of inquiry. To make this case, we present data from an inquiry workshop where a group of elementary school science teachers started from a common misconception, viewing forces as analogous to a substance carried by an object. Building on this metaphor, however, they construct a sophisticated Galilean explanation for why objects of different masses accelerate at the same rate due to gravity.

Section 1: Questions for dialogue

When engaging science teachers in inquiry as part of professional development, how strongly should facilitators prioritize eradicating misconceptions? What trade-offs exist between that goal and other goals of engaging teachers in inquiry, such as developing their sense of what science is? Under what conditions, if any, can teachers build on their "misconceptions" to reach productive understandings of concepts they will be teaching to their students.

Section 2: Conceptual framework

To present our framework clearly, it will help if we first describe the project in which it is embedded. Our MSP project focuses on keeping underrepresented students in the STEM pipeline through high school and into college. In one strand of this broader effort, we conduct professional development with grade 4-8 teachers aimed at helping them engage their students in scientific inquiry in the classroom. In this context, we define one element of "effective teaching" as science is teaching that helps students engage in inquiry, by which I mean the pursuit of coherent, causal explanations of natural phenomena.

An example will clarify this definition of inquiry. Consider the usual textbook explanation of why clouds form as part of the water cycle: When the water vapor gets high enough where the air is colder, it condenses. To increase the extent to which this explanation is *causal*, we would need to explain *how* the gaseous water molecules come together and stay together as tiny droplets, even though there doesn't appear to be anything like a cold windshield for the water vapor to condense *on*. A student seeking coherence would go even further by spotting and trying to resolve possible inconsistencies between this description of cloud-formation and other knowledge possessed by the student. For instance, if the cloud consists of tiny droplets, why don't those droplets start falling immediately? A student who has seen the standard demonstration of a light and heavy object falling at the same rate has reason to question a quick explanation such as "the droplets are so light that they 'float.'" In brief, we define inquiry as the attempt to "fit together" observations of and ideas about the natural world. In this process, discourse is just as important as experimentation.

To prepare teachers to engage their students in this kind of inquiry, we engage teachers in their own inquiry during summer workshops. In doing so, we emphasize the inquiry process at the expense of content coverage, sometimes spending 10-15 hours on a given topic exploring the teachers' follow-up questions to the original question. For instance, in the episode discussed in this presentation, the teachers had been grappling with the following original question: *If you're walking at a steady pace holding your keys in your hand, and you want to drop the keys so that they land on a particular spot on the floor, should you drop them before you reach that spot, or when the keys are directly over that spot, or after you've passed that spot?* The ensuing inquiry led to, among things, experiments in which we dropped objects out the window of a moving car, and discussion about whether an object's downward motion comes at the expense of its forward motion, and why or why not. The inquiry reached a point where the teachers wanted to understand why a heavy and light object fall at the same rate (when air resistance is negligible). They all *knew* this to be true, but they wanted to understand *why*; common sense says that the heavier object is getting pulled down harder and therefore should fall faster, and the teachers wanted to reconcile their common sense with their observations of falling objects.

This presentation addresses one piece of this broader research question: Can this kind of deeper inquiry — where we encourage teachers to explore ideas in depth even when some of those ideas are misconceptions — prepare teachers to engage their own students in inquiry? This presentation explores a particular piece of this broader question: What are the advantages and disadvantages of letting the teachers work through their misconceptions as part of their inquiry, rather than having the facilitators quickly confront the misconceptions and guide the teachers away from them?

Section 3: Explanatory framework

To explore this issue, we videotape the teachers engaging in their own inquiry over the summer workshops. Then, we videotape the teachers in their own grade 4-8 classrooms over the subsequent years. From the classroom videotapes, we can explore whether the teachers attend and respond to their students ideas (Sherin & van Es, 2009), encourage discourse and argumentation (Driver, Newton, & Osborne, 2000; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001), try to draw causal explanations (rather than just, say, just vocabulary words) out of students (Sandoval, 2003), and encourage students to seek coherence among data and ideas. We can also observe if the teachers are visibly imparting misconceptions to the students. From the workshop video of the teachers, we explore which aspects of inquiry the teachers themselves were engaged in, and the extent to which they were able to work through their own misconceptions.

In this presentation, we focus on a group of four teachers discussing the issue of why heavy and light objects fall at the same rate, and in particular, on the misconceptions that came up. We also briefly summarize our work-in-progress exploring the effects of this episode on one of the teacher's subsequent teaching, and we relate that finding to some general trends we are seeing in our data.

Section 4: Lessons learned

During their small-group discussion of light vs. heavy falling objects, a central misconception that "Ann" and the other teachers display is the idea that force (in particular, gravity) is analogous to a kind of "stuff." For instance, Ann makes an analogy between gravity and gasoline:

Well, with the car, here's a gallon of gas, it's like a gallon of gravity. That can pull 500 pounds worth of car. But, if I add another 500 pounds of car, that doesn't mean it's all of a sudden going to come down faster, what it means it needs its share of gravity as well. So it's going to be constant, as I add weight to it, I'm actually using a little bit more gravity...

Many researchers have argued that viewing force as substance-like rather than as an interactional process is a particularly pernicious misconception that *must* be confronted and nudged aside before the learner can make productive conceptual progress (Brookes & Etkina, 2009; Slotta & Chi, 2006). However, the instructor listening in on this group of teachers did not intervene.

Building on this "misconception," the teachers eventually formulated a coherent, correct explanation of why heavy and light objects fall together — an explanation very much like the one Galileo formulated when he first solved this problem. Ann presented that idea during the ensuing whole-class discussion:

Well we were really struggling with the germ of an idea, and we're not totally sure, but, we sort of have the idea that, like if you take a roll of quarters and one quarter, we know that if you drop them, they're going to land at the same time now. And to try to reconcile that, I was trying, we had a couple of analogies, I was trying to think of gravity as a constant force all over the earth, and in order to pull that one quarter down, it takes like 2 ounces, or 2 whatever, units of gravity to pull it down. So, when you just lump them all together, it doesn't change the fact that each one of those quarters in that roll is still going to need its little 2 whatevers of gravity, so putting them together doesn't make it any harder or any easier for it to come down, if each little part still needs that little bit of gravity, so if you thought about that coin roll, and slowly started separating them, just the fact that you're pushing them together doesn't, shouldn't really affect the fact that each need their own little bit of gravity, and we thought about a car as well...

During the subsequent whole-class discussion, other teachers built on this to construct the textbook Newtonian explanation for why heavy and light objects fall at the same rate: The heavier object indeed feels a greater downward force but it *needs* a greater force because its greater inertia makes it more difficult to speed up.

This episode illustrate a pattern we've observed over three summers, that letting teachers hash out their ideas over an extended time often enables them to construct productive explanations that build on their initial "misconceptions," without the instructors needing to confront those misconceptions.

Ann still refers back to this episode two years later, calling it formative in her emerging sense of what science is and what inquiry can be. And in her own classroom, Ann often lets students hash out ideas — even wrong ones — instead of quickly jumping in to confront them. Although Ann is unusually consistent in engaging students in such inquiry, many of the teachers we work worth regularly engage their students in inquiry, not just experiments but also authentic discussions. The effects on students' test scores have not yet been calculated. Our point in this presentation, however, is that deemphasizing "misconceptions eradication" in teacher professional development can help teachers rethink their views of what science and inquiry are and can help lead teachers to engage their own students in inquiry.

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Abstract Title:
The Rite Way to STEM Assessment

MSP Project Name:
The Rhode Island Technology Enhanced Science (RITES) Project

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Strand 3

Summary:
Effective STEM teaching is manifested in gains in content knowledge, increased use of technology, and a shift towards more discovery-based teaching. Assessment of progress towards these goals employs a variety of instruments that capture gains in content and shifts towards more discovery-based modes of teaching. This assessment of effective teaching begins in summer workshops, and continues with examination of teaching practices in the classroom throughout the following academic year. Beyond the workshops, we monitor the increased involvement of teachers in other STEM initiatives, changes in their attitudes towards science and inquiry-based methodologies, and measures of student success. Results from all of these measures of progress will be presented, along with a consideration of which instruments best predict effective teaching.

Section 1: Questions for dialogue at the MSP LNC
The RITES project provides supplemental PD (in the form of summer workshops and other efforts) to 6th through 12th grade science teachers in Rhode Island that emphasizes the innovative use of technology as the servant to inquiry-based teaching strategies. The premise is that if our PD is effective, it will result in more effective STEM teaching in K-12 classrooms. Questions that have emerged in our work, and which may well be of more general interest, include:

1. Of the variety of assessment tools available, as listed in Section 3 and in the summary of abstract, which are the most useful predictors for effective teaching?
2. There is general agreement that inquiry-based pedagogy---in which critical thinking, problem solving, and appreciation of science are emphasized---is needed. However, this style of teaching takes time, and inevitably results in less content being covered. With increasing emphasis on standard-based metrics for assessing the success of teaching, inquiry-based teaching strategies may place students at a disadvantage. How do we balance these contradictory stresses on contemporary teaching?
3. In Rhode Island there are many competing efforts to improve STEM education. How do we decide that our efforts provide true value-added, in this busy environment?

Our efforts and concerns should be of interest to other STEM faculty, evaluators, K-12 administrators, K-12 teacher leaders/professional development specialists.

Section 2: Conceptual framework

Effective STEM teaching is creative, responsive instruction that is (a) attentive to learner knowledge base, initially and evolving through a course experience, (b) rich in the use of inquiry, (c) supported by appropriate and efficient technology, and (d) contextualized by synergistic decision-making and curricular design on the part of school programs, schools, districts, and states.

Though widely recognized as critical to science teachers as they attempt to integrate inquiry-rich instruction into their practice, researchers have struggled to understand how to design PD that fosters classroom inquiry, is salient for a wide range of teachers, and is sustainable within district-university collaborations (Fullan, 1991; Wei, Darling-Hammond, Andre, Richardson, & Orphanos, 2009). In this study, we describe how several teams of secondary teachers and higher education faculty working within a statewide Math-Science Partnership (MSP) between district and higher education faculty designed and enacted PD to model inquiry instruction, foster teachers' buy-in and use of a collection of computer-based investigations designed to foster inquiry in grade 6-12 classrooms. We will address the following research questions:

The RITES project intends to reach the majority of grade 6-12 science students. How does RITES take into account the diversity of student backgrounds, and technology in schools?

The RITES project relies heavily on the premise that use of probe ware and software is an efficient strategy to foster student gains in content, critical thinking, and interest in science. Does our assessment bear this out? Or does it suggest that other strategies, such as fieldwork, are equally effective.

Which of the assessment instruments are most predictive of student achievement.

Section 3: Explanatory framework

In RITES we are using the following instruments to identify content gains and changes in teaching styles in teachers who participate in RITES: 1) pre- and post-surveys of discipline-specific content at the time of the short course, and during the subsequent year; 2) observation of workshop presentations using a modified RTOP (i.e., Reformed Teacher Observational Protocol) tool, and the application of the observational protocol to selected K-12 classes taught by teachers who had taken the short courses. In addition, both RITES and its external evaluator, the Alliance for Education at Brown University, are collecting data on student performance, as well as on effective teaching.

Section 4: Lessons learned

What aspects of our PD are of most value? Assessment of our PD indicated that, uniformly, teachers lacked a clear understanding of what constitutes effective inquiry-based teaching, despite have read about it. Starting in the third year we have placed a stronger emphasis upon the inclusion of inquiry-based activities in all of our PD, and a companion presentation (cf. Caulkins and Fogleman, this conference) covers our efforts in more detail.

What were the barriers to effective use of our PD? Our PD relies heavily on the use of probeware and web-based software that includes embedded assessment tools. It has become clear that the technology resources vary greatly from school to school, and we thus need to work with them individually in order to insure that our technology will be an asset, and not a liability, in the teaching of science.

What are the scientific concepts that teacher have the most difficulty grasping and presenting to students? Through the content assessment instruments we are able to get a clearer picture of what topics teachers find challenging. In many cases the choice is a reflection not so much of how complex a topic is, as it is a reflection of how or whether the material was ever taught in science courses that comprise the pre-service training of teachers. An example of this is the rock cycle, and a companion presentation (cf. Cardace et al, this conference) explores why teachers find this deceptively simple idea problematic.

Developing curriculum materials and PD that teachers find useful as they enhance the inquiry opportunities in their classrooms is a challenge. Within this statewide collaboration, district and higher education partners are committed to creating resources and PD experiences that have lasting value among teachers across the state. Curricular reform initiatives have often been criticized for being top-down (Fullan, 1991). This work contributes our understanding of how district-university partnerships can address difficult issues of practice in ways that meet teachers' needs and are judged salient by large numbers of teachers.

Abstract Title:
Attention to Teaching for Science Education Fellows

MSP Project Name:
Boston Science Partnership

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Strand 2

Summary:
The Boston Public Schools' Science Department defines teacher leadership as leadership in schools, the district or beyond that stems from excellent and recognized classroom practice with children and work with peers. To increase the number of teacher leaders and deepen their leadership skills, the Boston Science Partnership has supported a year-long fellowship for K-12 teachers of any science subject. This session will share the program design and components of the fellowship, such as the use of video, collaborative lesson study and personal plans which form the basis of the year-long fellowship. These components have led teachers to elevate the quality of their own classroom practices. The district has benefited by being able to focus the attention of teachers – both Fellows and their colleagues – on the importance and excitement of classroom instruction. Lessons learned provide direction for future efforts that aim to improve classroom practice for the teaching of science.

<u>Section 1: Questions for Dialogue at the LNC</u>

a. What does "teacher leader" mean?
b. How does classroom practice figure in teacher leadership?
c. How can a master teacher program (or fellowship) support *good* teachers to push themselves to become *great* classroom teachers?

Section 2: Conceptual Framework

The Boston Public Schools' Science Department defines teacher leadership as leadership in schools, the district or beyond that stems from excellent and recognized classroom practice with children and work with peers. As classroom practice is at the root of this definition, the Boston Science Partnership (BSP) sought to develop a master teacher fellowship program, with supplemental support by Noyce funding, to strengthen the force of teacher leadership in the district. By providing opportunities for Science Education Fellows to attend to improving classroom practice and exhibiting leadership among colleagues, the program's intent has been to strengthen the capacities of teachers in both areas. The project's definition of effective teaching in science includes facilitating opportunities for learners to explore concepts and connections in coherent ways across the years during which a child's education in science is built, as well as across STEM disciplines. That is, according to the BSP's definition of effective teaching in science, an effective science teacher is one who can use the district's science curriculum and also draw on other resources (both instructional and strategic) to help students build on what they have learned already, and to prepare students for what they will learn next in the sciences. Thus, teachers are able to make informed decisions about what to emphasize in the science curriculum, and they know what students should know and be able to do from earlier science learning experiences, so they can build on those experiences and also respond appropriately to cases where prior understanding is underdeveloped. The Science Education Fellowship (SEF) program, therefore, was designed to provide structured opportunities and ongoing support for SEF Fellows as they collaborate across grade levels and across STEM disciplines to study their own and each other's classroom practices, and to carry benefits from what they learn to other teachers in their schools and across the district.

A strong cadre of teacher leaders in Boston has been built over more than a decade through the MSP (2004-2012), its Phase II project (2010-2013), and the Urban Systemic Partnership (2001-2006) that formed the foundation for these. Many teacher leaders whose expertise as teachers was strengthened during these years have remained in the district and continue to fulfill leadership responsibilities, but good leaders still require ongoing support as well as stimulation and continued education toward continually improving their own classroom practice and leadership abilities. Additionally, many outstanding newer teachers have also taken on leadership roles in the district, and these teachers also need support to enhance their leadership capacity while also strengthening their classroom practice. Thus, we designed a program to increase classroom efficacy among teachers who were already taking leadership roles in the district. Typical leadership roles being fulfilled by these teachers include serving as: trainers for district-wide science instructional materials, peer leaders among AP science teachers in the district, co-instructors with STEM faculty in graduate-level science courses for teachers at the partner universities, and facilitators of school-based Collaborative Coaching and Learning in Science (CCLS, that is, a BPS developed professional learning community that is similar to Lesson Study), among others. Teachers typically enter these roles by volunteering themselves or by being recruited by district science staff, but the criteria for selection to these roles has not centered on demonstrated success in classroom practice. As a consequence, a wide range of expertise in classroom practice exists among the current cadre of science teacher leaders in the district.

The goals of the BSP's Science Education Fellowship (SEF) are:

- To support a focus on classroom instruction;
- To improve the culture of intellectual and effective reflection on teaching practice; and
- To support a culture of attention to classroom practice.

The program was designed to achieve these goals through teachers' participation in two main strategies: 1) CCLS groups (both horizontally in the same grade band across science disciplines, and vertically in the same discipline across grade bands), and 2) a personal plan for classroom leadership (which was called a Growth Plan System, or GPS). In addition, monthly professional development meetings, and assignment of each Fellow to a one-on-one mentor from among the project leadership, support both strategies. The program was designed to involve teachers in about 200 hours of professional development throughout the year. Funding to support the SEF program as a master teacher program came from two Noyce supplements to the MSP.

The evaluation was designed to understand the project's impact. Evaluation data were collected by external evaluators through observations of the professional development meetings, review of GPS plans, surveys of all Fellows and in-depth interviews with four Fellows. As well, project staff and PIs collected, reviewed and reflected on event evaluation data, reviewed artifacts created by Fellows throughout the program, and reviewed a sample of videotapes of the fellows' CCLS meetings. The evaluators participated in and observed planning meetings in order to have a solid understanding of the goals and underpinnings of the project.

Section 3: Explanatory Framework

As seen from the perspective of a Fellow, the Science Education Fellowship consists of three main components: monthly meetings, the CCLS cycles, and the individual plans or Growth Plan Systems (GPS). The monthly meetings provided introduction and theoretical background to the strategies, leadership training, support for developing the growth plan system (GPS), logistical and strategic planning, and other foundational support for the strategies in which the Fellows engaged throughout the year. Each Fellow developed an individual GPS, which went through a review cycle with the mentor and project director prior to finalization. The GPS formed the basis for regularly scheduled checks on progress throughout the year. The principal activity in which the Fellows engaged was CCLS cycles. This abstract focuses primarily on CCLS as it proved to be extremely valuable for the Fellows.

Collaborative Coaching and Learning in Science (CCLS) was developed during the early years of the BSP and refined throughout it. Adaptations were made to the original model. The original model (BSP's LNC presentation, 2009) engages groups of teachers, usually in a single school, who follow an 8-week long inquiry into practice and document their process. The process is guided by a teacher leader who has been trained as a CCLS facilitator and who receives support from Science Department staff. Each group consists of between 3 and 7 teachers. The group members collaborate to design a course of study, visit each other's classrooms to observe a complete lesson, examine an aspect of research on teaching, and provide warm and cool feedback to each other in a structured and safe format.

The structure of the SEF program necessitated modifications to the CCLS model. The SEF program organized teachers from across the district into vertical (same discipline, spanning grade levels) teams during the fall semester and horizontal (same grade band, different science disciplines) teams during the spring, requiring teachers to work with peers from other buildings and other grade band levels in two complete CCLS cycles. It was impractical for the Fellows to visit each other's classrooms in person to view the same lesson. The SEF modification of CCLS, therefore, had teachers use video as a proxy for in-person visits. In this way, teachers from various buildings, grade levels and locations around Boston were able to observe each other's teaching and teaching context. The videos gave teachers the opportunity to provide feedback to each other on real lessons delivered to real students, but they also offered another advantage. The use of video also afforded the opportunity for Fellows to observe themselves prior to the discussion about the lesson with their small groups.

Monthly professional development meetings included preparing the groups to follow the protocol of a CCLS cycle. We found it to be powerful to use a "fishbowl" approach to demonstrate the CCLS protocol elements, with narration to explicate each aspect of the cycle . It was important for all teachers to see what a CCLS meeting looks like by viewing teachers actually doing the work in order to prepare for their own turn in a CCLS group. Not only was the protocol new for some teachers, but others needed to see the modifications to the protocol as well as review challenge spots. For example, a difficult component of the CCLS process occurs when teachers are asked to provide warm and cool feedback to their peers. Often, this feedback can stray from direct comments to problem solving. The fishbowls enabled Fellows to role play and practice the restraint necessary to remain on task in the CCLS protocol before they engaged in it themselves. Another modification to CCLS was to employ rotation among group members in the facilitator role, so it was especially helpful to have all Fellows engaged in the fishbowl on CCLS. Very soon after groups were established in the fall, and again upon reorganization in the spring, groups coalesced and the structure of CCLS provided a supportive environment in which Fellows could expose their strengths and shortcomings among peers, integrate research on teaching and learning into their analysis and feedback, and challenge and support each other to grow in their classroom practice. Each Fellow served in the role of facilitator of the CCLS, providing a nurturing environment in which the Fellows could exercise leadership.
Each Fellow also developed and followed an individualized Growth Plan System, or GPS. The plans were initially drafted by the Fellows, and then were critically reviewed by program staff and mentors who helped the Fellows sharpen the ways in which they challenged themselves, and the methods they would use to hold themselves accountable to their goals. GPSs were very individual and varied considerably, but often included growth through activities such as mentoring a novice teacher, leading professional development activities in the district, piloting new instructional approaches with colleagues, learning about a particular area of science education research and how it could impact how teachers in the district could be supported, etc.. In the second year of the program expectations were tightened so that Growth Plan activities would directly support classroom practice, a modification that paid off in gains to teachers' own practice and in the experiences for all Fellows as the activities of the fellowship year were more cohesive.

Section 4: Lessons Learned

A number of findings and lessons learned have been gathered by the leadership team and through the evaluation of two cohorts of Fellows (n=39 unique teachers). These are briefly summarized below.

The annual evaluation report and discussions with evaluators and staff feedback provided us with direction to adjust elements of the program between the first and second year of the SEF program. The adjustments were intended to sharpen the focus on classroom instruction, tighten the communication of expectations, and respond to challenges in gathering classroom observation data about applicants prior to the design of the year and selection of the Fellows. Findings reported in the evaluation report from the second year of the SEF program indicate that these adjustments made a positive difference in how teachers made use of the SEF program.

The SEF program has been highly successful in accomplishing its goals, as concluded from multiple perspectives, including the Fellows, their school administrators, district administrators, and project staff and PIs. Below are summarized four main lessons learned from this effort that we consider to be more broadly useful to other projects that are implementing master teacher programs focused on improving classroom practice and increasing leadership capacity.

1. *Appreciation of High Quality Teaching*. Focus on teaching practice has furthered the message from the Boston Public Schools (BPS) Science Department that classroom teaching is exciting, stimulating and worthy of a great deal of attention. Because the SEF program was not focused on grooming good teachers for roles outside the classroom, the activities of the year changed the frame of reference for many teachers about what high quality teaching looks like. Over their fellowship year, Fellows grew to appreciate the changes to their own instructional practices, their relationships with other teachers, their knowledge of the BPS curriculum and the impact on their careers , the growth ahead of them, and that classroom practice is the heart of teaching.
The evaluation reported increased engagement in teaching, excitement about Fellows' own on-going professional growth, and a commitment to engaging in activities that would support that growth. Evidence of this includes that Fellows maintained connections with their CCLS groups, initiated building-based professional learning communities, and have continued participating in professional development opportunities as they arise.

2. *Use of Video*. This aspect of the SEF program was ambitious, and a number of challenges needed to be overcome, but they were mostly technical. Two primary benefits to using video (in contrast to in-person observations) emerged. 1) Teachers are able to view *themselves* teach, allowing for direct reflection on their own teaching approaches, and identification of their own challenges and opportunities, enabling a reflection that is otherwise very difficult to achieve. 2) Video archives a moment, and in this way it serves as a tool for reflection on changes to practice throughout the year of the fellowship. We found that it was particularly powerful when Fellows compared their videos created in the first and last months of the SEF program; this enabled them to see their own growth.

3. *Changes to Practice*. The focus on instructional practice has been well received, by the Fellows themselves, by their school administrators, and by district administrators. This focus has resulted in specific changes to practice, better reflection on the link between research and practice, and teacher leaders who continue to push themselves in the classroom. Linking the GPS and CCLS work provided a cohesive set of activities related to classroom practice.

4. *Strengthen Culture*. The SEF program has allowed the science department to strengthen a culture of reflective science teaching, starting with the selected teacher leaders, and flowing to teachers across the district. We have observed a stronger culture of growth among science teachers in Boston as the Fellows share the stories of their own growth over the year with their peers, and work with peers on additional projects spawned by their Fellowship year.

Abstract Title:
Effective STEM Professional Learning Communities—Learning from the Field

MSP Project Name:
MSP Knowledge Management and Dissemination Project

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Strand 2

Summary:
The Math and Science Partnership Knowledge Management and Dissemination project (MSP KMD) is charged with situating what the MSPs are learning in the broader knowledge base. One area of inquiry we have pursued involves STEM professional learning communities, an approach for improving mathematics/science teaching and learning that is included in a number of MSP projects. The MSP KMD project has collected and synthesized recent MSP research as well as the insights of experienced practitioners utilizing STEM PLCs as a key mechanism for enhancing teaching and impacting student success in mathematics and science. This session will address what we know from research and engage participants with the key practice-based insights of MSP leaders and other experienced practitioners on designing STEM PLCs.

Section 1: Questions for dialogue at the MSP LNC

What are the implications of research on the link between PLCs, effective teaching, and student success for MSP efforts?

How do the practice-based insights on designing STEM PLCs resonate with MSP leaders?

Section 2: Conceptual framework

Professional learning communities are an increasingly common approach for improving mathematics/science teaching and learning. The idea is that by working together, school-based groups of teachers can improve their mathematics/science instruction and, in turn, increase student success. A synthesis of research conducted by the National Commission on Teaching and America's Future (NCTAF) and WestEd indicated that PLCs can be effective in improving teaching and learning in mathematics/science (Fulton, Doerr, & Britton, 2010). The NCTAF study examined the current knowledge about the impact of PLCs on teachers' disciplinary content knowledge (DCK) and pedagogical content knowledge (PCK), instructional practices, student achievement, and teachers' job satisfaction and retention.

Unfortunately, the research literature does not provide much guidance about how to design a PLC in a given context in order to have a positive impact on classroom practice and student outcomes. The NCTAF synthesis project found that the research literature is very thin; only 33 research studies met their search criteria, and when standards of evidence were applied to the identified studies, the majority was judged to be of poor quality. In some cases, studies looked at a small number of teachers in depth, but did not explain how these teachers were selected, or the extent to which their prior backgrounds or experiences in the PLC were representative of the larger group of participants. In other cases, subjects were dropped from the studies with no explanation given or the impact of that attrition on the results. In addition, there were only five studies that explored the relationship between PLCs and student achievement. In both of these ways, the shortcomings of the knowledge base about PLCs is similar to those of the knowledge base regarding deepening teacher mathematics/science content knowledge and developing and utilizing teacher leaders (Heck, Markworth, & Weiss, 2010; Pasley, Smith, Taylor, & Heck, under review).

The Math and Science Partnership Knowledge Management and Dissemination (MSP KMD) was funded as a Research, Evaluation, and Technical Assistance project to support knowledge management within the MSP program and to disseminate information to the broader mathematics and science education community. The overall goal of MSP KMD is to synthesize findings in the K–12 arena in a small number of important areas, articulating the contribution of the MSP program to the knowledge base and identifying "gaps" and promising practices/strategies for further investigation. In this way, MSPs and the field at large can benefit from MSPs' research and development efforts. The MSP KMD process involves the collection and synthesis of both research-based findings and practice-based insights.

MSP KMD initially focused its knowledge acquisition and knowledge sharing efforts on deepening teacher content knowledge, teachers as intellectual leaders, and STEM faculty involvement in the K–12 arena. In the last year, the MSP KMD project focused its efforts on STEM PLCs to improve science and mathematics teaching and learning. MSP KMD staff collected and analyzed MSP research using the Standards of Evidence process developed by MSP KMD to operationalize best practices in empirical research (Heck & Minner, 2010). In addition, practice-based insights were collected from an on-line panel composed of representatives from MSP projects and other experienced practitioners using a process developed by MSP KMD to collect and synthesize practice-based knowledge (Miller & Pasley, under review).

Section 3: Explanatory framework

Teacher professional learning communities were a strategy utilized by many National Science Foundation Math and Science Partnership projects in their efforts to improve K–12 student learning in science, technology, engineering, and mathematics content areas. For the purposes of our knowledge acquisition, STEM PLCs were defined as groups of three or more teachers who met regularly over a sustained period of time and focused on improving STEM teaching and learning. MSP projects used STEM PLCs for a variety of purposes: as part of professional development aimed at deepening teacher knowledge, as a support strategy to help teachers transfer what was learned in MSP workshops into their classroom practice, and as a vehicle for MSP teacher leaders to work with other teachers. As part of their commitment to contributing to the body of empirical research in education, MSP projects have produced studies that examined both the operation of STEM PLCs and their effects.

MSP KMD staff collected and reviewed the MSP studies that included findings on STEM PLCs. A total of 13 MSP studies were identified by the MSP KMD project through direct requests to project leaders, a review of collected papers on MSPnet, and a review of project websites. The 13 studies went through a rigorous review using the Standards of Evidence process developed by MSP KMD. MSP KMD staff summarized the findings from the review of MSP research in this area, noting the contribution of the MSP research to the body of knowledge on STEM PLCs described in the NCTAF synthesis of research.

Practice-based insights on STEM PLCs were collected through multiple data collection efforts. First, program officers from NSF and the Department of Education identified projects which utilize PLCs and/or were conducting research on the PLCs. Next, a survey was sent to the approximately, 250 individuals who worked on those projects asking about the nature of their experience with STEM PLCs. A total of 51 individuals responded to this survey. Information from this data collection effort informed the selection of individuals for a second questionnaire. A follow-up survey was sent to 37 individuals to learn more about the nature of their experiences regarding STEM PLCs and to collect their initial thinking on factors that contribute to the effectiveness of the STEM PLCs. A total of 18 people responded to the second survey.

MSP KMD staff identified a group of 12 individuals, which included six MSP project leaders or evaluators, to serve on an online panel. Some of these panelists were identified through the on-line survey process; others were individuals who were known to have broad experience in working with or studying STEM PLCs. The online panel discussion involved two rounds of questions. The panel members were presented with various statements about STEM PLCs and asked to react to these statements. The analysis of panelists' responses in the first round informed the questions that were asked in the second round. The data generated from the panels were analyzed for central themes and summarized in a series of knowledge reviews that will be posted on the MSP KMD website in November 2011.

Section 4: Lessons learned

PLCs have become a familiar and popular feature in the professional development landscape, and STEM PLCs are found throughout the MSP programs. While the intention is that STEM PLCs contribute to improving mathematics/science instruction and student success, the pre-existing knowledge base about how and to what extent PLCs achieve those goals has been thin. The lessons learned from the empirical research and practice-based insights on STEM PLCs include:

Similar to other areas of education research, empirical findings in research on PLCs tend to be of a large grain size and do not provide very much guidance for practitioners on designing PLCs for impacting teaching and learning.

Insights of practitioners experienced in designing and implementing PLCs to improve STEM classroom instruction, when systematically collected and analyzed, provide valuable guidance to the education community and can serve as hypotheses for future research. A sample of those insights is listed below:

It's important to consider what you are trying to accomplish in determining the size of a PLC.

STEM PLCs should not be expected to address all of the needs for teachers' continuing education.

STEM PLCs may be more amenable to some professional development purposes than others.

Skilled facilitation is important to the success of STEM PLCs

Establishing group norms is essential to the success of STEM PLCs.

Protocols and tools can increase the likelihood that a STEM PLC will be successful.

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Abstract Title:
Affecting and Documenting Shifts in Secondary Precalculus Teachers' Instructional Effectiveness and Students' Learning

MSP Project Name:
Project Pathways: Phase II

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Strand 3

Summary:
The *Pathways Precalculus Professional Development Model* (PPDM) that includes focused workshops for teachers, in-class activities with detailed teacher notes, online videos and dynamic applets will be shared. Its design was based on lessons learned from Phase I research activities and findings. The PPDM student assessment data from over 30 Pathways precalculus classes revealed large gains in student understandings and ability to use the central ideas of precalculus. Analysis of data also revealed that improvement in teachers' content knowledge alone did not result in gains in student learning. However, when teachers were provided research designed, conceptually oriented curriculum, with focused workshops and instructional resources to support their implementation, large gains in student learning and teacher effectiveness were achieved.

<u>Section 1: Questions for dialogue at the MSP LNC</u>
What does it mean to have mathematical content knowledge for teaching precalculus (MKTP)?
How does a teacher's MKTP affect her teaching practice?
How has your project impacted teachers' MKT?
Have shifts in teachers' MKT resulted in shifts in their teaching effectiveness and students' learning?

<u>Section 2: Conceptual framework</u>
Project Pathways Phase II has a primary goal to affect secondary precalculus teachers' instructional practices so that teachers are able to: i) support students in constructing deep understandings and rich connections among central ideas of precalculus; ii) support students in developing problem solving abilities that entail *ways of thinking* and *ways of approaching* complex tasks that include accessing and using key concepts as needed to solve novel problems;

iii) interpret and act on student thinking when teaching; iv) improve student learning, and v) reflect on student thinking and learning in relation to teaching. This definition of effective teaching emerged from studying teachers in relation to their knowledge, curriculum, and classroom practices during Pathways Phase I research. Our findings consistently revealed that improvements in teachers' content knowledge for teaching precalculus had little impact on their teaching, curriculum, or exams, even when explicit efforts were made to support the teachers in designing more conceptually oriented tasks to use in their teaching. The teachers' understandings of the content knowledge they were teaching (e.g., MKTP) were fragile and lacked necessary connections for interpreting student thinking, posing meaningful questions, constructing conceptually oriented exams, and providing conceptually oriented explanations when teaching. This finding led us to consider other interventions that would support precalculus teachers in continuing their development of MKTP towards improvements that we hypothesized would result in their becoming more effective teachers, as described above.

Relevant Research on Content Knowledge for teaching

According to Bryan (2002), a number of studies that investigated the knowledge of prospective secondary mathematics teachers have revealed that prospective secondary mathematics teachers, even with a substantial amount of university mathematics coursework completed, still may not have a level of conceptual understanding of their future subject matter that is needed for teaching. Other studies of pre-service secondary mathematics teachers also reported that prospective secondary mathematics teachers do not have a level of conceptual understanding that supports student learning of key mathematical ideas (Bush, Lamb, & Alsina, 1990; Even, 1993; Wilson, 1994). Silverman and Thompson's (2005) study of pre-service teachers' conceptions of function suggests that "despite the fact that the pre-service teachers did develop a more robust, coherent understanding of functions as covariation of quantities…their instruction remained grounded in a procedural approach that involved memorizing a definition" (p. 1). In a later study Siverman & Thompson (2008) reported that even when secondary mathematics teachers do transform their personal understandings of the mathematics, this transformation may not result in subsequent transformations in their pedagogical conceptualizations.

Drawing from this work, our Phase I intervention provided a four-course, research based, sequence of graduate courses designed to improve teachers' understandings of the content of courses they teach. Concurrent with their enrollment in the course teachers met for 3 hours in weekly PLCs. The PLCs were led by a facilitator who was mentored in managing quality discourse about student thinking and learning of specific content. The results of investigations of these Phase I interventions extended the body of knowledge related to content knowledge for teaching preclaculus, by revealing that courses that are effective in improving inservice teachers' understanding of key mathematical ideas of precalculus, accompanied by focused PLCs, are also not sufficient to realize dramatic shifts in teaching effectiveness and student learning.

Phase I findings led to the development of the Pathways Precalculus Professional Development Model (P3DM) that includes: I) in-class student activities with detailed teacher notes that articulate both desirable and undesirable ways of thinking for each question within each activity; ii) computer animations and PowerPoints designed to support teachers in leading conceptually oriented discussions designed to support students in engaging in quantitative and covariational reasoning (Carlson, Jacobs, Coe, Larsen, Hsu, 2002; Moore & Carlson, in press); ii) exams and other assessments to support precalculus teachers in evaluating student learning (Carlson, Oehrtman & Engelke, 2010); iv) professional development workshops that are required prior to using the P3DM instructional materials and tools. Our research has examined the impact of P3DM relative to our criteria of effective teaching.

Phase II builds on Phase I findings in five broad categories that are critical for supporting mathematics teachers to realize significant shifts in their students' learning of key ideas of mathematics, teachers': 1) deep understanding of the central concepts of a course, their connections and the process by which students learn and are able to use these concepts to solve novel problems (e.g., Carlson & Rasmussen, 2009); 2) ability to engage in *reflection on student thinking and learning* in relation to their teaching; 4) use of curricular support materials that promote inquiry-based and conceptually oriented instruction (e.g., Moore, 2010; Strom, 2008); and 5) participation in Pathways Professional Learning Communities (PLCs) (e.g., Carlson, Bowling, Moore, Nieves, 2008; Oehrtman, Carlson, Vasquez, 2009).
The Phase II Research Agenda is studying the following questions:

1. What aspects of the P3DM model are contributing to the development of secondary mathematics teachers' mathematical knowledge for teaching precalculus?
2. What is the typical trajectory by which P3DM teachers become effective precalculus teachers?
3. What attributes of the P3DM model are contributing to secondary precalculus teachers shifting to become effective teachers?

Section 3: Explanatory framework

Our research of P3DM is providing valuable insights about the process by which secondary precalculus teachers become more effective teachers. We are learning that teachers are capable of making rapid and significant gains in their MKTP and ability to: i) support students in constructing deep understandings and rich connections among central ideas of precalculus; ii) support students in developing problem solving abilities that entail ways of thinking and ways of approaching complex tasks that include accessing and using key concepts as needed to solve novel problems; iii) consider student thinking and using student thinking when teaching; iv) ability to improve student learning, and v) ability to engage in *reflection on student thinking and learning* in relation to their teaching. A study of 12 teachers using P3DM revealed highly significant gains in their class mean scores on the precalculus concept assessment (PCA) instrument[1]. The mean PCA gain for the precalculus courses being taught by P3DM trained teachers ranged from 5.5 to 9 (out of 25), with a mean post score of 15.5 as compared to high mean PCA post score of 10.2 from over 40 classes of college level precalculus courses. Our early data also supports that students of P3DM are well prepared to succeed in calculus.

Variables that appear to be critical for achieving these shifts include teacher professional development that is provided in the context of specific curricular tasks that teachers are using when teaching the central concepts and content of a course, in this case, precalculus. In our phase I work teachers were constrained by the curriculum they were using. Analysis of clinical interview video data and videos from teachers classrooms revealed that teachers' images of the mathematics they were to teach was tightly linked to their current textbook and the mathematics

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[1]The PCA is a research instrument that has been validated to assess student understanding of key ideas that are foundational for understanding ideas of calculus. It has also been validated to correlate with student success and failure in calculus (Carlson, Oehrtman & Engelke, 2010).

they had been taught when in high school. They also did not have the research knowledge or writing expertise that is necessary for developing conceptually coherent curriculum tasks that develop the ways of thinking that lead to deep and connected understandings of a course's central ideas. As a result, it was impossible for teachers to supplement their existing curriculum in meaningful ways. In addition to professional development that is tied to the curriculum for students, it is also critical that teachers are supported in understanding the common correct and incorrect ways of thinking that may be evoked by each curriculum task and question. These supports are what make it possible for teachers to promote quality student thinking and to react effectively to student thinking and understandings when teaching. This led to our decision to operationalize research knowledge of what is involved in understanding and learning key ideas of precalculus (e.g., proportion, constant rate of change, function, increasing and decreasing functions and rates of change, exponential growth, periodic growth). We conducted a series of 3 teaching experiments to develop and refine student tasks and teacher support tools for teaching each key idea of precalculus (e.g., Carlson & Oehrtman, 2004; Carlson & Rasmussen, 2008; Strom, 2008; Moore, 2010; Moore & Carlson; in press)[2] Research designed assignments can also be highly effective in helping teachers gain valuable feedback they need for evaluating their student learning.

Section 4: Lessons learned

We initially hypothesized that if teachers were supported in constructing deeper understandings and connections among the concepts they teach, they would be motivated and able to support their students in also acquiring these understandings and problem solving abilities. Our results revealed that even after four conceptually oriented graduate courses that modeled inquiry based instruction, most teachers made only minor shifts in their instructional practices to interject more questions and group work into their lectures. However, the content focus continued to be dictated by the course textbook that typically focused on carrying out steps to answer specific problem types. We underestimated the amount of support teachers would need to make the dramatic improvements in their teaching, and significant gains in student learning, that we had initially proposed.

We also learned that PLCs are generally more effective if they have a strong facilitator who holds teachers accountable for demonstrating quality reasoning and coherent explanations, and that are focused on content that a group of teachers are currently instructing. We also found that all pedagogical decisions of the teachers are linked to the teachers' current understandings and ways of reasoning about the ideas that they are the focus of a lesson. As well, teachers who have robust understandings of ideas, how they are connected, and how they are learned have powerful lenses for examining student thinking and for making effective decisions toward advancing student learning when planning for teaching and when responding to students during teaching.

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Abstract Title:
Assessing Mathematical Habits of Mind for Teaching

MSP Project Name:
Focus on Mathematics, Phase II: Learning Cultures for High Student Achievement

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Summary:
Focus on Mathematics is a targeted MSP funded by the National Science Foundation since 2003. As part of this work, we are developing a research program with the goal of understanding the connections between secondary teachers' mathematical habits of mind (MHoM) and students' mathematical understanding and achievement. We are developing tools to study the question: What are the MHoM that high school teachers use in their professional lives and how can we measure them? In this session, we will share our working definition of effective teaching and describe how that definition is shaping the development of an assessment to measure MHoM.

Section 1: Questions for dialogue at the MSP LNC.

How do teachers use mathematical habits of mind in their professional work?

What does it mean to measure teachers' mathematical habits of mind?

What does research tell us about design of discipline-focused teacher leadership and professional development?

Section 2: Conceptual framework

Building on close to two decades of prior work, the Focus on Mathematics MSP has, over the last eight years, developed and refined a distinctive framework for a mathematics-centered approach to developing teacher leaders and it has built a mathematical community based on that framework. The Focus on Mathematics approach involves teachers, mathematicians, and mathematics educators, all working in programs that put mathematics at the core of a tightly connected set of professional development activities, including intense immersion experiences in mathematics and school-based study groups that include teachers and higher education faculty. These activities, taken either individually or in tandem, are examples of what we will call a mathematical learning community.

We believe that participation in a mathematical learning community produces career-changing improvements in teaching practice. We have documented evidence of significant positive impact both to the 5–12 community and to the mathematicians and their teaching at the post-secondary level. As our sense of these mathematical learning communities matured, refinements to the approach and new questions became apparent; as the communities themselves matured, new information became available. Accordingly, we began a second phase of work to deepen the community of the existing partnership, to scale up the work, and to conduct research on some questions that have emerged over the past five years that are of considerable interest to the field. In particular, we have been studying mathematical knowledge for teaching.

The notion of mathematical knowledge for teaching (MKT) has been studied by many researchers [3, 21, 49, 1, 26, 27, 17, 18, 19, 24]. Our understandings of this notion parallel much of what we have read in the literature, but are based on our particular experiences over the past 20 years, as mathematicians engaged in doing mathematics with secondary teachers. As one part of the work of Focus on Mathematics, we proposed to develop a research program with the ultimate goal of understanding the connections between secondary (grades 7–12) teachers' mathematical knowledge for teaching and secondary students' mathematical understanding and achievement. Distinctive of our approach is the core involvement of mathematicians in all aspects of the work.

As mathematicians working in schools and professional development we have come to understand some of the ways in which teachers know and understand mathematics. These fit into four large and overlapping categories:

> (1) They know mathematics as a scholar: They have a solid grounding in classical mathematics, including its major results, its history of ideas, and its connections to precollege mathematics.
>
> (2) They know mathematics as an educator: They understand the thinking that underlies major branches of mathematics and how this thinking develops in learners.
>
> (3) They know mathematics as a mathematician: They have experienced a sustained immersion in mathematics that includes performing experiments and grappling with problems, building abstractions from the experiments, and developing theories that bring coherence to the abstractions.
>
> (4) They know mathematics as a teacher: They are expert in uses of mathematics that are specific to the profession, including the ability "to think deeply about simple things" (Arnold Ross), the craft of task design and the "mining" of student ideas.

The first two of these ways of knowing mathematics are common to most pre-service and in-service professional development programs. Focus on Mathematics has paid particular attention to the last two, which typically receive less emphasis. We've become convinced that (3) greatly enriches and enhances the other ways of knowing mathematics and that many teachers who go through such an experience develop the habits of mind used by many mathematicians. Furthermore, we have seen that participation in a mathematical learning community helps such teachers "bring it home" in the sense that they create strategies for helping their students develop the mathematical habits that they themselves have found so transformative. This leads us to conjecture that a component of mathematical knowledge for teaching at the secondary level is teachers' mathematical habits of mind that are enhanced or developed through participation in mathematical learning communities. The emerging theory of mathematical habits of mind is philosophically grounded in Dewey's earlier treatment of habits and habits of mind [7, 8]. Dewey's seminal work has since encouraged educators [11, 28] and education researchers [23, 43, 50] to further operationalize the concept of habits of mind. That is, to respond to the general question:

What do habits of mind look like in the context of learning?

Some answers to this question include: (1) questioning evidence; (2) imagination; (3) being clear and careful; (4) thinking about thinking; and (5) thinking flexibly. Not as evident in the literature are the habits of mind that promote successful learning in specific disciplines. In the case of mathematics, the question that has gained research attention within the last decade is:

What do habits of mind look like in the context of learning and doing mathematics?

While addressing this question is not an unfamiliar task [15, 39, 40, 41], what is less familiar is the task of gathering evidence of mathematical habits of mind from professional mathematicians and translating them to K-12 classrooms [16, 44]. Researchers responding to this challenge include Cuoco, Goldenberg, and Mark [6] and Driscoll [9, 10].

Our working definition of an effective teacher is one who can foster these mathematical habits of mind in his or her students. Our work with secondary teachers has led us to believe that when teachers begin to develop their *own* mathematical habits of mind, there is a positive effect on their classroom instruction. We recognize the need for a scientific approach to investigate our beliefs. Our current work is focused on developing the tools to carry out these investigations.

An example of effective teaching

We will illustrate with an example how secondary teachers use mathematical habits of mind to carry out the work of teaching. “Peter” is an 8th grade math teacher, in his eighth year of teaching at the secondary level. For the past five years, he has been an active member of the Focus on Mathematics learning community. As part of our current research, we observed a lesson in Peter’s Algebra 1 class.

The mathematical topic of the day was recursive rules. As Peter noted in his pre-interview, his students already have basic knowledge of functions as input/output tables and some familiarity with the function notation. Building on what students have learned in prior years, Peter hopes to solidify their understanding in this lesson, especially their facility in *using* the function notation. Both in his pre- and post-interviews, Peter emphasizes the overriding goals for his students (that is part of *every* lesson): (1) performing explorations to seek patterns and make conjectures, and (2) generalizing from concrete examples and repeated calculations. He adds that this particular topic of recursive functions lends itself well to serving these goals.

Peter begins the lesson by giving his class a recursive rule that is incomplete: “The output for a given input is 3 greater than the previous output.” (Note: It’s missing the base case.) Students experiment with this rule, creating tables and trying to derive closed-form equations. In the discussion that follows, Peter uses the structure that students had uncovered to motivate the formal definitions of *recursive rule* and *base case*. From their table of data, students deduce and write relationships such as $f(2) = f(1)+3$ and $f(5) = f(4)+3$. And using these concrete examples, they derive a more general equation: $f(n) = f(n-1)+3$.

Almost 20 minutes into the lesson, Peter finally introduces the complete notation

$$f(n) = \begin{cases} 5 & \text{if } n = 0, \\ f(n-1)+3 & \text{if } n > 0. \end{cases}$$

Instead of being a starting point, this notation is the *culmination* of the structures that students discovered through their experimentation and the follow-up discussion. Students readily make sense of the new notation, because the experiences gained through their "struggles" allow them to connect the new language to already-established ideas. The students then spend the remainder of class working on more problems involving recursive rules.

Peter concludes the post-interview by describing how today's particular lesson is part of a bigger unit and how it sets the foundation for later lessons. "We're going through an in-depth study of functions," he says. He plans to use these recursive rules as vehicle for better understanding their closed-form counterparts. In particular, the class will later investigate the connection between linear and exponential functions. "I want my students to see that recursively, exponential functions are very, very similar in its representation to linear functions. I think that will provide a nice foundation for studying exponents." Here, Peter is using his own MHoM, in particular his knowledge of the *structure* of functions, to make *pedagogical* decisions. His own structural understanding allows Peter to provide his students with effective opportunities to learn substantial mathematics, and treat the mathematics with intellectual integrity (Bruner, 1960).

In fact, at the end of today's lesson, Peter gave his students a preview of things to come. He asked them to compare the two recursive functions:

$$f(n)=\begin{cases} 5 & \text{if } n=0, \\ 3+f(n-1) & \text{if } n>0. \end{cases} \qquad g(n)=\begin{cases} 5 & \text{if } n=0, \\ 3\cdot g(n-1) & \text{if } n>0. \end{cases}$$

He also challenged them to find a closed-form rule that matches $g(n)$. In one of his sections of Algebra 1, this problem led to discussion about 3 to the zero power. "I knew that there was a chance that would happen, but I hadn't exactly planned on it. When it happened, certainly I wanted to acknowledge it and see where it went. But in my other section, we didn't end up having that discussion. And that's fine. We'll get there when we are thinking about exponential functions specifically."

Theoretical Framework for Focus on Mathematics.

As a theoretical basis for our work, we use the frameworks developed by Clarke and Hollingsworth [5] for their "Interconnected Model of Teacher Professional Growth," which is characterized by networks of "growth pathways" among four "change domains" in teachers' professional lives—the external domain (E), the personal domain (K) (of knowledge, beliefs and attitudes), and the domains of practice (P) and salient outcomes (S). We use these designations (E,P,K,S) to classify the kinds of change we see in our outcome goals and benchmarks. Significant, from our point of view, is the Clarke-Hollingsworth theory of professional growth (as distinct from simple change), which they represent as "an inevitable and continuing process of learning." They aptly distinguish their framework from others: "The key shift is one of agency: from programs that change teachers to teachers as active learners shaping their professional growth through reflective participation in professional development programs and in practice" ([5], page 948). The agency of teachers in their own professional growth characterizes virtually all Focus on Mathematics programs, so we see the Clarke-Hollingsworth model of professional growth as well suited for our purposes. We illustrate the framework of [5] with an example. Shown in Figure 1 is a change environment diagram for "Emily," a middle school teacher and active member of the FoM learning community. The diagram represents the change domains as four boxes, labeled E, K, P, and S, as explained above. The solid arrows refer to changes due to enactment, while the dashed arrows depict those due to reflection. The loop on the box E refers to interaction between study groups and the immersion, also represented by the two vertical arrows in the smaller diagram on the right.

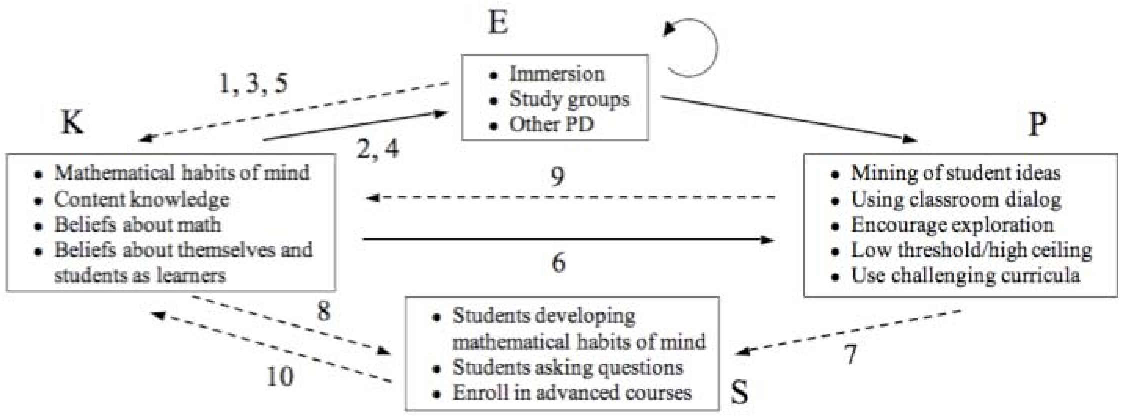

Figure 1. Schematic diagram of Emily's change environment

This particular diagram depicts activity related to research Emily conducted on Pythagorean Triples and shows how this activity led to her growth, both mathematically and as a teacher. She first encountered the concept of Pythagorean Triples while studying Gaussian integers during a summer immersion experience. The topic left such an impression on her (reflective arrow 1) that she pursued it (enactive arrow 2) as a research project under the guidance of an FoM mathematician. Through months of hard work—familiarizing herself with Pythagorean Triples through dozens of examples, making careful data recording and analysis, discovering beautiful patterns, coming up with interesting conjectures (some were true, some were false), and finally writing down clear and concise propositions and proving them—she came to understand (reflective arrow 3) features of Pythagorean triples that would have been beyond her conception before this experience. Emily produced an independent research paper and a one-hour mathematics talk for her peers (enactive arrow 4).

Neither the summer immersion experience nor the independent research project was easy for Emily, who came into our program with a rather weak mathematics background. But completing this project had a significant effect on her mathematical self-confidence (reflective arrow 5). The loops of this upward spiral between domains K and E repeated many times. Amongst her peers, Emily became one of the leaders in her study group (4). In her curriculum planning, she now has more belief in her decision-making abilities (5). And in her classroom, she engages her students in performing mathematical exploration (6). This new classroom atmosphere, as well as her new attitude towards mathematics, led to more curiosity and questions from her students (7, 8). And while she may not be able to answer all of them on the spot, she now welcomes mathematical dialogs and uncertainty in her classroom (9, 10). All of this represents significant professional growth and Emily's change diagram enables us to see the elements of that growth "at a glance" (Polya).

Looking at Emily's change diagram, one cannot fail to notice the intense activity taking place around the node K, which includes growth in Emily's knowledge of mathematics. But it seems to us that more is involved than simply knowing mathematics as a body of knowledge. Emily is learning mathematics in a certain way. Her beliefs about the nature of mathematics are changing. She is acquiring certain mathematical habits of mind and she is finding these habits useful for her work in the classroom and also for leadership roles in the school.

Section 3: Explanatory framework

The Focus on Mathematics MSP has a number of mechanisms for gathering evidence of effective teaching. In our LNC session, we will focus on the first phase of our development of a long-term research project. This initial phase of our research centers on the following question:

What are the mathematical habits of mind that high school teachers use in their professional lives and how can we measure them?

Specifically, we are developing two assessment instruments: a paper and pencil assessment of mathematical habits of mind for teaching, and a classroom video observation protocol. Many excellent tools have been developed in recent years for studying the work of mathematics teachers. [20, 25, 42, 12, 22, 46, 4]. In developing our own assessments, we are drawing insight from all of these projects, but will most closely follow the assessment model developed by Ball, Hill, and others. Their assessment measures "specialized" mathematical knowledge—that is, the knowledge that teachers use, as distinct from the mathematical knowledge held by the general public or used in other professions—whose components include representation of mathematical ideas, careful use of reasoning and explanation, and understanding unique solution approaches. These skills resemble the kinds of mathematical habits that we are interested in studying, at the high school level.

The focused research study has developed and piloted a paper and pencil assessment that measures the nature and degree of mathematical habits of mind for teaching and can be used as a pre and post measure in relation to professional development experiences such as those offered by the Focus on Mathematics and other MSPs. This assessment is undergoing its fourth revision based on three pilot tests.

The development and validation of a truly reliable paper and pencil assessment that can be administered to a large number of teachers, such as those developed by Ball, Hill, and others, is beyond the scope of our initial phase of research. Although our instrument will be provisional in this sense, we are using what we are learning from the preliminary data to inform our professional development work throughout the Focus on Mathematics MSP.

In our session, we will give examples from the paper and pencil assessment as well as offer participants an opportunity to use the rubrics we have developed to code participants responses to the assessment questions.

Section 4: Lessons learned

A. Lessons Learned in Professional Development

Over the past eight years, we have learned a tremendous amount. Although we continue to keep mathematics and content-based professional development at the core of everything that we do, a key lesson has been our growing recognition that content-based professional development is necessary but sufficient for supporting teachers' professional growth.

To that end, we have created additional vehicles to help teachers bridge from the mathematics experiences they have as part of Focus on Mathematics to their classroom. One such vehicle is the weekly "Number Theory Shadow Seminar" created as part of PROMYS, our summer immersion program. The Number Theory Shadow Seminar has become an integral component of the summer immersion program. The seminar focuses on the following three questions:

1. What does it mean to know mathematics as a mathematician, and how does such knowledge

influence the teaching of mathematics at the secondary level?
2. What pedagogical aspects of the PROMYS program, if any, make it different from the other mathematics classes that you've taken in the past?
3. Is it possible to bring the pedagogical approach of the PROMYS experience into a secondary mathematics classroom? If so, how? If not, why not?

The goal of this seminar is to explore (a) the ways in which secondary teachers know and use mathematics in their profession, (b) how to bring the pedagogical philosophy and style of PROMYS into the secondary mathematics curriculum, and (c) the effects that such a learning environment might have on secondary students.

To work towards this goal, the teacher participants:

- engage in discussions about their PROMYS experiences and how the PROMYS pedagogy might be adapted and applied to the secondary curriculum,
- read, analyze, and discuss articles on Mathematical Habits of Mind and on what it means to know/do mathematics as a mathematician,
- study examples of how former PROMYS teacher participants have adapted and used the PROMYS pedagogy in secondary classrooms, and
- design lessons grounded in the PROMYS pedagogy that may be used in their own classrooms.

B. Lessons Learned in Research

Two main themes emerge in the lessons we have learned in our research project. First, we need to clarify how our *research* work is rooted in secondary teachers' practice. Second, we need to be more concrete about some aspects of our theoretical framework and constructs. Both themes are guiding our current work.

B1. Tying our work on MHoMs to the work of secondary mathematics teaching.

Feedback from the field has been strong: we need to be clear about how our constructs and assessments are rooted in classroom practice. We are committed to doing this without diluting our emphasis on the mathematics, and have sought feedback on this. For example:

- Several advisors have recommended that some of our assessment problems be rooted in or connected to classroom practice. New versions of the assessment based on this feedback were piloted in June, July, and August.
- We wouldn't feel the assessment was successful if teachers could score well but not use math well in their classroom practice. We've been advised to find ways to "check," even at this early stage of development of the assessment, that high performance on our assessment suggests that teachers can *use* mathematics well in their professional work. We will discuss this at our LNC session.

B2. Being concrete about the Mathematical Habits of Mind.

We've gotten two types of feedback on all of the work of our project. We've gotten lots of constructive criticism, much of which we have been able to implement in each round of the assessment pilots. When we present items from the assessment to advisors or at working sessions at professional meetings, we don't encounter any lack of clarity. When we present our lists of actual habits of mind (our constructs), we do encounter confusion. We've heard from some sources that they are too abstract, so we have developed a new way of organizing and streamlining our constructs for this project.

We decided to focus our attention on one particular way of thinking about mathematics: the importance of underlying structure. The mathematicians and teachers we surveyed and interviewed confirmed our own sense of the importance of structure in doing mathematics. We are looking at how teachers:

- seek,
- use, and
- describe underlying structure

for themselves, and how they provide experiences for students to seek, use, and describe underlying structure. Three examples of using structure in secondary work include:

1. Polynomials, complex numbers, matrices all behave in similar ways – the underlying vector space structure allows you to learn about all of them at the same time.
2. Reasoning about calculations or purposefully transforming algebraic expressions – for example, reasoning that the maximum value of $-x^2+6x-4$ must be 5, because $5-(x-3)^2$ (a transformed version of the first expression) is at most 5.
3. Generalizing from repeated calculations.

This emphasis on structure dovetails very well with the Mathematical Practices of the Common Core State Standards.

We have collected data from multiple field tests of the assessment in Summer 2011. We have rubrics developed from actual data sets, and in doing so we are "building backward" to a concrete description of "seeking, using, and describing structure."

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Abstract Title:
How Do You Know if Your Project Is Resulting in Effective STEM Teaching?

MSP Project Name:
Mathematically Connected Communities-Leadership Institute For Teachers (MC^2-LIFT)

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Summary:
The MC^2-LIFT project has a strong research component which provides frequent feedback to the staff and participants in relation to meeting its purpose of developing mathematics teacher leaders. Researchers have been able to measure progress towards our definition of effective STEM teaching. The research team is also able to share findings with our institute development team and school support team who can use the data in developing revised content and modifying school support. This presentation will share our research design, research questions, methodology and instrumentation as well as current findings. So far findings indicate that it is possible for teachers with significant support to make positive changes in as little as one year in the quality of their mathematics teaching.

<u>Section 1: Questions for dialogue at the MSP LNC</u>

1. How well do the research design, the research questions and the methodologies used, fit with the project goals?
2. How have the findings from research been used to shape and modify the teacher leadership institute?
3. What findings are most useful in terms of answering the question of what is effective STEM teaching?

<u>Section 2: Conceptual framework</u>

Our definition of effective STEM teaching is: creating an environment in which students actively engage in problem solving and mathematical dialogue. Effective STEM teaching facilitates learning for *all* students as they engage in cognitively demanding tasks. The teacher designs the classroom environment so that students have sufficient opportunities for reasoning and sense making which result in useful mathematical knowledge, skills, and dispositions. Effective STEM teaching requires the teacher's continual development of their professional content, pedagogical knowledge and skills, and relies on feedback through ongoing assessment of what students are understanding and not understanding.

The MC^2-LIFT project personnel are organized into three teams. The Development Team develops and facilitates the institute courses. It is comprised of both mathematics educators and research mathematicians. The Research Team gathers, analyzes, and shares data regarding the actual changes in classroom practice and teacher's knowledge that result from the coursework and school-based support. The Research Team includes an internal evaluator, external evaluators, and mathematics educators and researchers. The School Support Team works with LIFT teachers in their classrooms and during institute courses, helping them apply what they are learning in their Institute courses. Its members include mathematics educators and former public school teachers who also participate in Development Team meetings, helping to ensure that what they see in classrooms shapes the development of institute courses.

In order to have effective mathematics teaching, we believe that public school teachers need to have a strong background in mathematics and how to teach mathematics content. They also need to be strong in research-based pedagogical practices; in particular, they need to know how to facilitate a student-centered classroom with a heavy emphasis on activities leading to deep understanding and good synthesizing of learning. Our institute courses are designed to give the teachers content and pedagogical knowledge, and the institute facilitators also model good teaching practice. Notably, we make great efforts to model the launch/explore/share/summary lesson structure and facilitator questioning, rather than lecturing and answering questions. The study of mathematics through vertical trajectories creates a learning environment with multiple entry points, many landing places, and high ceilings. Institute work is designed to integrate mathematics and pedagogy, and to require application of institute learning to the teacher's classrooms and schools.

In terms of Strand 3 of the conference, which relates specifically to how teachers and project leaders can know if they are moving successfully toward meeting the goals of the institute, we have evolved effective ways to collect and analyze data and share findings. This allows us to provide both general and teacher-specific feedback to the institute staff and to the participants. This will be discussed further in later sections.

Section 3: Explanatory framework

The original purpose of the research group for MC^2 LIFT was twofold: 1) to study the effect of the institute on participating teachers' knowledge, skills, and dispositions for mathematics teaching, learning and leadership; and 2) to investigate the development and implementation of the institute and its implications for mathematics education. As the project evolved it became increasingly important to the institute leaders to provide more frequent feedback of the research findings to the staff in order to improve the institute courses. It also became important to evolve additional ways to provide feedback to the participants themselves. The following tables show the main research questions, the methodology and instruments used, and the evolution of the research design. The instruments themselves will be shared as part of this presentation as well as findings from the first cohort of 31 teacher participants.

Overarching Research Question 1: How do teachers change as a result of participation in the institute in relation to the following areas: a. Knowledge of K-12 mathematics, b. Pedagogical practices, c. Leadership in their schools and districts			
Sub Question to be Answered for Overarching Research Question 1	**Instruments / Measures Used to Answer the Question**	**Timeline**	**Findings and Changes**
1a. How do teacher's knowledge of K-12 mathematics change as a result of participating in the institute?	MKT (Univ. of Michigan) *Mathematics Knowledge for Teaching*	Summer Academy (TKAS (MKT) starting in 2011-12)	The MKT did not show positive gains when used as a yearly measure. It does however show positive gains when used as a pre and post test during short professional development.
	Pre and Post test related to math in each course	Each semester	Pre/post tests show positive gains for all teachers on math knowledge, especially elementary teachers. Useful in guiding planning for instruction
1b.As a result of participating in the institute, how do teachers *change* their teaching practice?	MTASK Instrument (Korn, 2010).	Each Spring	Teachers' self-perceptions of leadership is changing from what they do for their principals, to how they can mentor other teachers.
	Classroom observations using the Classroom Snapshot Instrument and OLE (SUMA research team, 2010).	Observation of Learning Environment (OLE) instrument used for observations 2 times each semester	Positive changes in classroom environments in terms of teacher behavior toward inquiry and mathematical content Teaching.
	Principal Focus Groups	Twice a year	External Evaluators Report
	Participant Interviews		External Evaluators Report
	Lesson Study Observations	Began Spring 2011	Lesson study helped the teachers move toward a more objective view of teaching, with more discussion of student learning than previously.
	MLE Reflection Instrument. Math Learning Environment	Began Spring 2011 Development team	MLE was developed to go with the OLE so teachers can reflect on changes in what will be measured in classroom environments.
1c. How do participants' perceptions and actions related to leadership change as a result of their participation on the institute?	LIFT Leadership Survey for teachers and principals	Leadership is emphasized in Year 2 All teams	Just beginning to look at research on leadership. Interest evolving in studies on types of communication and interactions between teachers and administrators during meetings.
	Observations of PLCs and SAVI coding.		

<table>
<tr><td colspan="4">Overarching Research Question 2: What is the effect of these teacher changes in math knowledge and pedagogy on student learning and achievement?</td></tr>
<tr><th>Sub Question to be Answered for Overarching Research Question 2</th><th>Instruments / Measures Used to Answer the Question</th><th>Timeline</th><th>Evolution of the research design</th></tr>
<tr><td rowspan="2">2a. Do the students of teachers who participate in the institute achieve at a higher level than students of teachers who did not participate in the institute?</td><td>New Mexico Standards Based Assessment (NMSBA)</td><td>Administered each spring (results by the summer)</td><td>Working on this t-test and getting data from partner districts.</td></tr>
<tr><td colspan="3">Design: t-test; matched pairs using a stratified random sample based on the demographics of the students</td></tr>
<tr><td rowspan="2">2b. What correlations, if any, exist between changes in teacher practices (as measured on the OLE and Snapshot), changes in teacher knowledge (as measured on the MKT and/or other instruments), and student achievement of mathematics (as measured on the NMSBA)?

Which factors seem to have the most effect on student achievement?</td><td>New Mexico Standards Based Assessment (NMSBA)</td><td>Administered each spring (results by the fall)</td><td rowspan="2">Will be able to use structured equation modeling to look at relationships of all measures when second cohort is added to first cohort so we have 60+ participants.</td></tr>
<tr><td>Classroom observations using OLE- tool and the classroom snapshot</td><td>2 observations each semester</td></tr>
</table>

Overarching Research Question 3: How is the institute developed and enacted and what can be learned from the implementation of this institute that can be helpful to the larger field of mathematics education for teachers?			
Sub Question to be Answered for Overarching Research Question 3	**Instruments Used to Answer the Question**	**Timeline and Responsibilities**	**Evolution of Research Design**
3a. How do mathematicians and mathematics educators work together to develop and implement the program courses?	Focus interviews with mathematicians Focus interviews with math educators	Each semester	External evaluators
	Records of agendas and meeting notes of teams Reflections of teams	Development Team Meeting Notes. Reflections by Development team on changes for second cohort.	Team leaders to provide meeting notes summaries.
3b. What kind of feedback is provided by the teacher participants on the courses and how is this feedback integrated by the development team into further course development?	Feedback form at the end of each institute session	Collecting Feedback at end of each session as well as at the end of each semester and summer session. Collection of evaluations for each course. Currently being compiled and analyzed by the research team	
	Course evaluations		
3c. How are the participants transferring their coursework into practices at their schools?	OLE and Snapshot instrument	Two observations each semester by researchers	First observations done by both the researcher and the school support person. Discussion/Plan
	Mathematics Learning Environnent Reflection Instrument (MLE)	Designed for teachers to use for self-reflection. Aligned with the OLE	Self-reflection tool used by participant teacher and as part of clinical supervision by support staff.
	Lesson Study		
3f. What are the personal and systemic barriers to developing and implementing the LIFT coursework and how were these resolved?	Focus interview with the management team	Management team consists of leads of three research teams	Evolution of cross – team groups to increase cross team management and development of grant

Section 4: Lessons learned

As a result of growth in the mathematicians and educators who have now worked together over the last five years, LIFT was designed to integrate pedagogy and mathematics while focusing specifically on what teachers are expected to teach in their classrooms. LIFT explicitly links what the teacher participants are learning to student math standards and each teacher's student achievement data. For instance, during our study of geometry, teachers used their own student achievement data to analyze their students' strengths and weaknesses in geometry. Our development team considered student achievement data in choosing which areas of geometry would be most relevant for study in the institute. As teachers learned about geometric concepts across the K-12 curriculum, they designed an instructional unit to address students' weakest areas in geometry.

LIFT developers have taken the idea of developing a vertical trajectory in mathematics that evolved in the MC^2 summer academies as a key component for teacher learning in the LIFT institute. They have also learned to design learning experiences that capitalize on the strengths of both elementary and high school teachers. LIFT development staff has employed intentional strategies to shape a K-12 mathematics professional learning community into a culture of collective trust.

Here are a few of the lessons we've learned in the first two years of the LIFT project.

- Work in LIFT courses is improving teachers' content knowledge, based on pre/post data.
- Teachers are improving in creating a Standards-based learning environment, based on OLE data. Gains are not uniform, and do not extend into periods of standardized testing.
- We have also learned to provide teacher-to-teacher support systems which seem to be necessary to help teachers redefine themselves as leaders. When the institute first began, teachers were preoccupied with "becoming the math expert" so they could be an effective math leader. However, the project goal is not to develop authority figures but, rather, to develop leadership skills that foster a collaborative professional learning environment. We realized that if we want teachers to develop as teacher leaders who collaborate with others to improve classroom practice, rather than continuing as dispensers of knowledge, it was necessary to model a reflective and collaborative learning environment for teachers in the cohort.
- Elementary teachers often lack confidence in their mathematics abilities when paired with secondary math teachers. Secondary teachers had a tendency to want to "rescue" the elementary teachers rather that help them develop their own mathematical thinking. The interesting dilemma is that elementary teachers often were much better able to describe their mathematical thinking from a conceptual framework than secondary teachers who often relied on memorized procedures as part of their solution methods.
- The development team learned strategies for classroom discourse to highlight the richness of elementary teachers' mathematical thinking. The instructors also learned to intentionally scaffold the class discussions to encourage elementary teachers to share their conceptual understanding and make connections to procedures presented by secondary teachers. The scaffolding of discussion by the mathematicians and

mathematics educators proved to benefit both elementary and secondary teachers and has resulted in increased confidence by the elementary teachers. They are now comfortable and confident in working with high school teachers. The high school teachers are now appreciating the elementary teachers search for meaning behind the use of procedures as well as the insights the elementary teachers provide.

- It is important to give effective feedback and to build useful mechanisms for peer feedback. Our use of unstructured peer feedback wasn't working, and moving to structured peer feedback is starting to make peer feedback helpful to the LIFT teachers.

Abstract Title:
Developing Dffective Math Teaching: Assessing Content Knowledge, Pedagogical Knowledge, and Student Success

MSP Project Name: Mathematics Teacher Transformation Institutes (MTTI)

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Strand 3

Summary:
The Mathematics Teacher Transformation Institutes (MTTI) program attempts to develop math teacher leaders in part by providing content, inquiry and leadership courses aimed at making them more effective teachers. We assessed progress by observing their teaching practices, and encouraging them to introduce or extend inquiry-based pedagogy in their classrooms. We found there was little relationship between our measures of math content knowledge and effective teaching. But teachers who employed student-centered, inquiry-based pedagogy tended to be more effective as math teachers, at least if effectiveness is assessed by the extent to which their students were engaged in the lesson. We also found that we needed to broaden our concept of student success from the time we submitted our proposal.

Section 1: Definition of effective STEM teaching

MTTI is a MSP program in which second-stage Bronx middle and high school teachers (4-10 years' experience) build their leadership skills. They do this by enhancing their knowledge of, appreciation for, and sophistication in mathematics, articulating and pursuing classroom-based inquiry projects, and engaging in direct leadership development.

MTTI's implementation plan is grounded in a theoretical logic model that presumes an interrelated causal chain. The model may be characterized as follows:

Learn advanced mathematics ↔ Improve pedagogy ↔ Acquire leadership skills ↔ Lead

The following two research hypotheses relate to effective STEM teaching: 1) teachers will improve their content and pedagogical skills over time and, therefore, their abilities to explain terms and concepts to students, interpret students' statements and solutions, and engage students in critical, in-depth, and higher-order thinking; and, 2) the development of reflective practitioners within a multi-dimensional effort to foster teacher leadership will have a positive impact on student learning. Thus effective mathematics teaching is seen as an important attribute of an effective teacher leader. In general, effective mathematics teaching is defined by its results, in this case improved student achievement in and enjoyment of mathematics. The question is what form of teaching is most likely to bring about these improvements?

The research component of MTTI seeks to broaden the knowledge base on teaching and learning in mathematics through new understandings of how the study of conceptually-challenging mathematics—particularly in algebra and geometry—benefits second-stage teachers; of how classroom-based inquiry contributes to critical and analytical understanding of the relationships between teaching practices and student learning and; of how multi-levels of support prepare second-stage teachers for leadership roles.

Educators, educational researchers, and policy makers have not always agreed about the elements that constitute effective teaching. For some, many mathematics teachers have inadequate mathematical content knowledge themselves, and thus are unable to teach their students to the highest level (Ahuja, 2006; Ginsburg, Cooke, Leinwand, Noell & Pollock, 2005). This position leads to the assumption that an increase in teachers' mathematical content knowledge will increase their effectiveness as mathematics teachers. Others (National Council of Supervisors of Mathematics [NCSM], 2008; National Council of Teachers of Mathematics, 2000) relate such an educational failure not only to the lack of qualified teachers with solid content knowledge in STEM, but also to the lack of a profound understanding of teaching and learning in grades K-12. For Brown and Borko (1992), and Ball and Bass (2000), content knowledge and understanding of the methods of inquiry in mathematics are at the core of effective teaching and learning.

The use of inquiry-based approaches to instruction, in which students have opportunities to construct their own understanding of basic concepts, has been found to be most appropriate in developing students' understanding of mathematics and science concepts. Such approaches call for teachers to be able to engage students in critical, in-depth, higher-order thinking through use of manipulatives, technology, cooperative learning and other pedagogical approaches that enable them to construct mathematics concepts on their own through reasoning, verifying, comparing, synthesizing, interpreting, investigating or solving problems, making connections, communicating ideas and constructing arguments (Grouws & Shultz, 1996; National Council of Teachers of Mathematics [NCTM], 2000). These approaches depart in significant ways from what occurs in "traditional" classrooms.

MTTI aims to supplement math teachers' content knowledge and help teachers make and sustain fundamental shifts in practice. Such changes should result in more effective teaching and teacher leadership. In turn, effective math teaching should lead to increased student success in math. Student success in math can be defined in various ways. The definition of student success that is considered in this study will encompass two elements: the level of student engagement as described through the observations; and MTTI teachers' description of their students' success as it relates to their action-research projects conducted over a period of one to two years.

Section 2: Gathering and analyzing evidence of effective STEM teaching.

Improving teachers' math content knowledge.

The two MTTI courses one in math fundamentals and the other in geometry took place throughout the spring and fall semesters of 2009. To assess teachers' math content knowledge two test designed by the University of Louisville, one in algebra/ideas and the other in geometry/measurement, were administered before and after the relevant content courses were completed. Each test contained 40 items overall. The items on these tests were general in nature. In addition, two tests designed by MTTI math faculty, one in math fundamentals, and the other in geometry were similarly administered. These tests were directly related to the appropriate course content.

<u>Findings</u>: Mean scores on both the MTTI fundamentals course-content test and the University of Louisville test of algebra/ideas increased significantly from pre- to post-test. Scores on the MTTI geometry course content test also increased significantly from pre- to post-test. However, mean scores on the University of Louisville test of geometry/measurement did not differ significantly from pre- to post-test. We found that the majority of MTTI teachers did not have responsibility for teaching geometry. Rather they were responsible for preparing students for state assessments related to algebra/integrated algebra. Moreover, the content of the Louisville geometry/measurement test was not well aligned with the geometry content covered in the MTTI course.

<u>Improving teachers' pedagogical knowledge and skills</u>.
According to our analytical framework, the second component of a math teacher's capacity for teacher leadership concerns their mastery of pedagogical practices appropriate both for their students and for the mathematics concepts they teach. Information about this component comes from, questions on Louisville algebra/ideas and geometry/measurement tests, classroom observations, and teachers' work in the classroom-based inquiry courses. Each is outlined below:

a) *Responses to pedagogy questions on the Louisville tests*

   Two Louisville tests, in algebra/ideas and in geometry/measurement, were administered before and after the relevant content courses were completed. Each test included 40 items overall. Ten of these items on each test related to pedagogical content knowledge. The scores on these 10 items were analyzed separately from the scores on the other 30 questions.

   <u>Findings</u>: The average number of correct answers, for the ten questions of the Louisville Algebra and Ideas test relating to pedagogical content knowledge increased significantly from 4.44 to 5.16 across test administrations. This suggests that MTTI participants' pedagogical content knowledge for algebra and ideas increased following engagement with a course in the fundamentals of mathematics. However, the mean pedagogical content knowledge scores for the Louisville Geometry and Measurement test declined slightly from pre-post administrations, but this decrease was not significant. We hypothesize that the lack of improvement in the Geometry and Measurement test may have been due to the lack of fit between the MTTI geometry course, which was designed to correspond to New York State's secondary geometry curriculum, and the items on the Louisville exam. In addition, fewer MTTI teachers had experience in or were currently teaching geometry as opposed to algebra.

b) *Observations of classroom practices*

   Beginning in the fall 2009 term, trained observers observed MTTI teachers' classrooms at least four times each term. Through January of 2011, 265 observations had taken place. The classroom observation protocol contains information about: key indicators of inquiry-based instruction; types of instructional activities (lecture, student presentation, group work, class discussion, etc.); student engagement, student cognitive activity, and the observer's overall assessment of the quality of the lesson.

Findings: Evaluation of teachers' classroom practices resulting from multiple observations of participants over a two-year period, revealed increases in the amount of classroom time MTTI teachers devoted to allowing students to practice mathematics. In addition, there was clear evidence that MTTI teachers shifted their pedagogical orientations. MTTI teachers made less use of strictly teacher-centered techniques and more use of student-centered approaches over time. This shift, making use of both teacher- and student-centered techniques, might be described as a hybrid orientation and is not as subtle as it may seem. In NYC schools, teachers are mandated to deliver mathematics instruction in the form of a workshop model: Lessons must be segmented in terms of "do now"; "mini-lessons"; "practice"; "assessment;" and, "summary". We believe MTTI participant's re-orientations—allowing students to practice mathematics more and adoption of hybrid teaching techniques—indicate an influence of this program that suggests teachers exercised greater discretionary judgments about both what their students needed and where to place emphasis under school conditions with prescribed pedagogical structures.

c) *Classroom-based Inquiry Courses*

The classroom-based inquiry course occurred throughout the spring and fall semesters of 2010. Growth in teachers' pedagogical knowledge through the classroom-based inquiry courses was examined through: i) teachers' reflections as contained in their classroom-based inquiry reports, in their course blogs, and in their open-ended course evaluations; ii) quantitative self-ratings from their fall 2010 course evaluations, and iii) the course instructors' analyses of final projects, observations, and teacher blogs.

Findings:

i) In their open-ended course reflections, most teachers (18 out of 27) identified growth in the related areas of becoming a more reflective teacher, understanding and being able to conduct inquiry-based teaching, and learning to pay greater attention to students' needs, prior knowledge, and understanding. Teachers also reported how they began to use some specific techniques or practices that they had not employed previously. Nineteen reported using at least one new technique or practice, eight mentioned error analysis, four mentioned formative assessment, and two mentioned classroom inquiry.

ii) In their quantitative self-ratings at the end of the course, most (78%) teachers rated themselves highly in their ability to identify and describe the errors and misconceptions in mathematics that their students committed/held; in designing activities to address these misconceptions (74%); in collecting and analyzing student data (70%); and reflecting upon the results of their classroom research (70%).

iii) An analysis of the teachers blogs indicated that many of the teachers were able to do several things that they had not been able to do at the beginning of the course sequence; namely to conduct meaningful inquiry projects based on their students' experiences, and to link their projects to prior research.

Section 3: What types of evidence inform progress toward more effective STEM teaching?.
Capturing the quality of classroom mathematics instruction is an elusive endeavor. The classroom observations outlined above attempted to look at this complex construct through three different lenses: 1) key indicators of inquiry-based instruction; 2) the extent to which the teacher used student-centered pedagogy, and 3) the observer's overall impressions of the effectiveness of the lesson. Each of these gross measurements has its shortcomings, but taken together it is hoped that they will allow for a general evaluation of the effectiveness of the lesson.

The data revealed slightly contradictory trends. For the key indicators of inquiry-based instruction, there was little change over the course of the project. In general, teachers used student-centered teaching for about one-third of the time, teacher-centered pedagogy for another third, and pedagogy that could not be clearly classified for a final third. On the other hand, observers' overall rating of the effectiveness of the lesson increased from fall 2009 to fall 2010.

Section 4: How our MSP assesses progress toward more effective STEM teaching.
We hypothesized that, if the MTTI participants' teaching was becoming more effective, we should see improvement in their students' attitudes towards and achievements in mathematics as demonstrated by the classroom observations and their responses to the MTTI teachers' action research activities.

Students' attitudes and performance
a) Observers' Reports: Student Engagement
In the fall 2009, spring 2010, and fall 2010 semesters, observers assessed the level of student engagement in math class at five-minute intervals. They recorded three possible levels of engagement: low engagement (80% or more of students off-task); medium engagement (mixed engagement); and high engagement (80% or more of students engaged). High engagement increased from fall 2009 to spring 2010. In the spring semester, high engagement had increased significantly from about 40% of observations to 63.5% of observations. Thus high-level student engagement increased significantly in MTTI participants' classrooms as the participants completed more of the MTTI program.

b) Observers' Reports: Student Cognitive Activity
For the fall 2009, spring 2010, and fall 2010 semesters, observers recorded the levels of cognitive activity in which students were engaged in the classes. The scale goes from the lowest, 1, or "receipt of knowledge," through 2, "skill building", 3 "knowledge representation" to 4 "knowledge construction." In general, received knowledge and skill building occurred significantly more often than knowledge representation and knowledge construction. However, there was an increase in skill-building activities and corresponding drop in receipt of knowledge from fall 2009 to spring 2010. This pattern of cognitive activity was maintained in fall 2010.

c) Student Outcomes of Classroom-based Inquiry Reports
Overall, 1017 students, 639 from high school and 378 from middle, were involved in 29 classroom-based inquiry projects developed by 22 teachers. In their fall course evaluations, teachers were asked to evaluate the impact that their projects had had on participating students. Seventeen or 63% of the 27 respondents reported that they had observed at least some impact of the action research projects

on their students. Nine reported positive changes in attitude towards learning math or participating in class; seven saw improvements in math performance; two saw changes in student meta-cognition, and three reported changes in students' verbal or written communication about math (four reported change in more than one area.) Four teachers reported having quantitative evidence, in the form of student tests or quizzes, to support their observations.

Section 5: What is the intersection between K-16 student success and effective STEM teaching?

Relationship between Student Centered Teaching Practices (SCT) and Student Engagement.

To determine if there was a relationship between SCT and student engagement, we derived two groups of participants; Group A (High SCT) consisted of the six participants who were observed to display the most student-centered teaching techniques as assessed by the classroom observers across both the fall 2009, spring 2010 and fall 2010 semesters; and Group B (Low Student Centered) consisted of the six MTTI participants who exhibited the least student-centered teaching techniques assessed in the same manner across the same time period. For Group A, the average percentage of time spent in student-centered teaching activities was 48.7% (s.d.= 9.0) across all semesters, while for Group B, it was only 15.7% (s.d.=9.2).

We then examined the relationship between student centered teaching and student engagement. We calculated the levels of student engagement for the two groups (high and low SCT) for each semester and a mean value across semesters. We found that students of Group A (high SCT) teachers were significantly more likely to be highly engaged in their math classes than students of Group B (low SCT) teachers.

Section 6: What our MSP knows now about measuring progress toward more effective STEM teaching that we did not know at the time we wrote our proposal?

We found that MTTI teachers' content knowledge in the fundamentals of mathematics improved significantly as a result of their participation in the program. However, there was little relationship between teachers' increase in content knowledge and their effectiveness as math teachers or their leadership activities. This may have been because the measures we used to assess content knowledge did not adequately tap into participants' pedagogical content knowledge. Most rated their self-efficacy for teaching content appropriate to the grade level and subject matter they were teaching very highly. In addition, the classroom observers never reported that the teachers did not have mastery of the content they were teaching.

We discovered that teachers who employed student-centered, inquiry-based pedagogy tended to be more effective as math teachers, at least if effectiveness is assessed by the extent to which their students were engaged in the lesson. We also found that teachers who employed student-centered teaching practices more often than teacher-centered practices were more active in teacher-leadership activities.

Assuming that student success in math is an outcome of effective math teaching, we found that MTTI participants had many and varied ideas as what, for them, constituted student success. MTTI teachers often understand student success in terms of attitudinal changes and motivation towards math, as opposed to test scores and grades. Although passing state-mandated tests was also seen as an important indicator of success. At the proposal stage, we tended to view achievement on state tests as the main indicator of student success. Now we realize that we have to broaden our view, and hence measurement of, student success and, by implication, effective teaching.

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