

Deepening Teacher Content Knowledge for Teaching: A Review of the Evidence

Iris R. Weiss and Barbara Miller
Prepared for the Second MSP Evaluation Summit
October 4-5, 2006

Introduction

The Math and Science Partnership Knowledge Management and Dissemination (MSP KMD) project was funded as an MSP Research Evaluation and Technical Assistance effort to support knowledge management within the Math and Science Partnership program and to disseminate information to the broader mathematics and science education community. The overall goal of the KMD project is to synthesize findings from MSP work and integrate them into the larger knowledge base for education reform. In this way, MSPs (both NSF-funded and Department of Education-funded) and the field at large can benefit from MSPs' research and development efforts.

The KMD project is conducting its work in a few important, carefully selected areas of mathematics and science education research and practice. The project uses a three-stage knowledge management model, created by Nevis, DiBella, and Gould (1995) for workplace settings. The model posits that learning occurs in three identifiable stages: *knowledge acquisition*, *knowledge sharing*, and *knowledge utilization*.

Deepening teachers' content knowledge is the first area to be investigated. As part of the knowledge acquisition phase for deepening teacher content knowledge, the project has identified key theoretical perspectives; conducted a literature review; and reviewed MSP documents and interviewed a number of MSP PIs and others to capture practice-based insights. These three sources—theoretical perspectives, research-based findings, and practice-based insights—will be integrated in syntheses that represent the field's knowledge base on selected topics and the contribution of the MSP program to the knowledge base.

Theoretical Framework

Research on effective teaching up until the late 1960s and early 1970s focused on teaching behaviors such as classroom and time management and techniques of questioning. Out of this research, it was hoped, powerful practices could be identified and broadly replicated through pre-service and continuing education for teachers. Specific subject matter concerns and attention to teacher knowledge were nearly absent from this research.

A turning point in this research related to the compelling and logical argument that teachers' knowledge of the subject matter they teach—science or mathematics—is an essential ingredient of their ability to teach that content to their students. By extension, it was hypothesized that

enhanced teacher content knowledge would increasingly support their ability to teach well. This contention became the basis for research on effective teaching in the ensuing decades. Begle (e.g., 1972, 1979) conducted landmark studies of teachers' content knowledge and students' achievement. Operationally, these studies investigated students' test scores as predicted by their teachers' higher education background in mathematics coursework.

Although the results of Begle's studies showed weak and inconsistent relationships, they served as a beginning to a line of work that has remained very active to the present day; this work has included both studies in which student learning has been examined as an outcome (e.g., Monk, 1994), and others in which the quality of teaching has been investigated as the outcome of interest. (See Choi & Ahn, 2003.) The results of additional studies have continued to provide important, if often inconclusive and conflicting, results. Ball, Lubienski, and Mewborn (2001) point out that the inability of research to establish the strength or nature of these relationships is not necessarily an indicator that these relationships are weak or non-existent. More likely they arise from a lack of specification of the nature of the content knowledge that is pertinent to the act of teaching, and consequently poor measurement of it.

Dewey (1897) hinted at the special nature of teachers' content knowledge more than a century ago in his characterization of the "psychologizing" of content knowledge that accompanies teaching. Essentially Dewey recognized that teachers conceptualize content knowledge for the purpose of teaching it in ways that are qualitatively different from its conceptualization within the disciplines that generate that content knowledge or within fields that apply that content knowledge.

Shulman (1986, 1987) pushed the work on teachers' content knowledge forward when he identified aspects of the knowledge base for teaching, including three content-specific domains of knowledge: subject matter content knowledge, pedagogical content knowledge (PCK), and curricular knowledge. In short, subject matter content knowledge comprises the theories, concepts, and principles of a discipline, as well as the approaches to generating and verifying ideas; PCK is "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1987); and curricular knowledge is understanding of how ideas are introduced, sequenced, and connected in instructional materials or courses. Of these domains, PCK has received the most scholarly attention over the past 20 years, largely because it provides a language and a platform upon which to base studies of teachers' content knowledge as it relates to specific aspects of the work of teaching. In more recent years the use of the term PCK has lessened in favor of the term "content knowledge for teaching." In part this shift may have occurred because additional aspects of the specialized content knowledge of teachers have been identified that were not delineated by Shulman. Lumping all of these aspects into PCK obscured the continued specification of the content-specific knowledge base of teachers. Also, the importance of subject matter knowledge appears to have been subordinated as PCK gained attention. Recently scholars have been paying more attention to teachers' subject matter knowledge, or disciplinary content knowledge, and finding that it is highly relevant and not easily distinguished from other aspects of content knowledge that are important to the work of teaching.

Following from Shulman's work, a line of research has emerged at the core of studies of teacher content knowledge to investigate the nature of the content knowledge that is most relevant and helpful to the work that teachers do. This research has highlighted the fact that the content knowledge that science or mathematics teachers need in their jobs is different from that which scientists or mathematicians need, and different from that which other professionals who use science or mathematics need in their jobs (e.g., those in health or finance fields). The specific nature of content knowledge that teachers of science or mathematics need, however, remains a subject of serious scholarly research and debate (Ball et al., 2001; Gess-Newsome & Lederman, 1999).

Over the past 20 years, a number of sub-domains have been proposed to further define teacher content knowledge in mathematics and science. In particular, pedagogical content knowledge has received considerable attention in theoretical writings and empirical studies. The result is a substantial body of work that has identified a variety of content-specific knowledge domains specifically related to teaching mathematics, such as:

- Knowledge of disciplinary mathematics and science content;
- Knowledge of student thinking about mathematics and science content;
- Knowledge of instructional strategies for teaching mathematics and science content;
- Knowledge of mathematics and science content as addressed (e.g., sequenced, connected) in curriculum; and
- Knowledge of applications of mathematics and science content.

These domains have been identified in an attempt to characterize important aspects of teachers' content knowledge. Rarely, if ever, is one of them proposed as the only aspect of teacher content knowledge that matters; few would argue that any one of the domains is unimportant for teaching. However, in specific instances of research or practice, it is often evident that one or more of these domains holds primacy. The primacy of one or a combination of domains typically falls into one of three perspectives on teachers' mathematics and science content knowledge (Ball, Hill, & Bass, 2005).

According to the *advanced knowledge perspective*, the content knowledge of key importance for teachers is understanding of the major foundational ideas and the nature of the mathematics and science disciplines (Askey, 1999; Cuoco, 2001; Wu, 1997). This perspective derives from the position that K–12 education should establish the foundation for students to develop both knowledge and appreciation of the major concepts and unifying ideas, as well as the epistemologies and methodologies, of the disciplines. Knowledge of disciplinary content is the domain of central interest, and deep understanding is the goal. The content is generally considered *advanced* because it includes knowledge of topics well beyond grade-level content, although deep, highly interconnected knowledge of grade-level content, which Ma (1999) terms *profound* understanding, may also be included.

The *content knowledge for teaching perspective* (e.g., Ball & Bass, 2001; Ball et al., 2001), is primarily concerned with content issues that arise in the course of teaching practice. This perspective focuses on the fact that the instructional decision-making teachers do in planning, carrying out, and reflecting on lessons depends on their ability to use mathematical or scientific

knowledge. When teachers choose tasks to assign, ask questions of students, interpret students' responses, and assess students' understanding, they employ content knowledge in ways that are distinct from the ways that academic mathematicians and scientists, or those working in applied fields, use their content knowledge. Ma (1999) explicated how teachers organize their knowledge of content as "knowledge packages" of closely related ideas that teachers use to think about instruction and student learning. These knowledge packages consist of "decompressed" knowledge of content, breaking down topics into very specific, key understandings that can guide interpretations of student thinking and instructional decisions. Of primary importance to this perspective are knowledge of disciplinary content, knowledge of student thinking about content, and content knowledge of instructional strategies. In terms of disciplinary content, the focus is typically on *profound* understanding of grade-level content

The *grade-level content perspective* arises from the fact that the nature and scope of content teachers are expected to teach throughout the K–12 curriculum is changing, especially evident in the "standards movement" at the national and state levels. Instructional materials developers have responded to the changing content in national and state standards by adding new topics or moving topics from one grade level to another. As a result, there is much content in national and state standards and curriculum materials that teachers may not have encountered in their own education, including their pre-service preparation. The upshot is that teachers may be unfamiliar with content ideas they are required to teach. The grade-level content perspective on teacher content knowledge emphasizes the perhaps obvious importance of teachers understanding the content they are teaching, essentially with the same depth students are expected to attain at that grade. Expected content understandings are neither profound nor advanced, aside perhaps from some knowledge of the articulation of content ideas from grade to grade in the K–12 curriculum. Knowledge of disciplinary content at the K–12 level, and knowledge of the curriculum, are the central domains of interest for this perspective.

The Review of Empirical Literature

KMD developed a system for conducting reviews of empirical research literature intended to ensure a transparent process with integrity and protections against bias in all phases. This process is outlined below in three parts: identifying studies for the review, summarizing and applying standards of evidence to the studies, and describing MSP-supported research.

Identifying Studies for the Review

The parameters for search and selection of studies were intended to yield a set of studies with a tight focus on the mathematics and science content knowledge of in-service teachers. To be included in this review, each study had to meet all of the following criteria:

- Teachers' mathematics or science content knowledge was studied empirically, through a specific measure (e.g., multiple choice test, open-response written items, interviews) or through systematic analysis of samples of teachers' work;
- The subjects or participants in the study were practicing in-service teachers within grades Pre-Kindergarten through 12; and

- The study was published since 1990.

Search parameters for the review were identified by initially searching on a set of keywords in ERIC, including:

- Teacher knowledge and mathematics/science;
- Teacher content knowledge and mathematics/science; and
- Pedagogical content knowledge and mathematics/science.

Results of these searches were examined to identify several studies that met the criteria for the review. Once identified, the ERIC descriptors for each of these studies were recorded. From these descriptors, the complete set of search parameters was developed and entered as a keyword search into ERIC and EBSCO Professional Development Collection.

Between mathematics and science, the searches yielded close to 2,000 articles. A member of the MSP-KMD team read the abstract, and skimmed the study if needed, for each study identified through this search process to determine its initial inclusion based on the criteria for the review. Close to 90 percent of the articles were eliminated in this initial screening. In most instances, the study did not include an objective measure of teacher content knowledge. Others were in fact not studies (e.g., they were advocacy pieces) and/or dealt solely with pre-service teachers. The search and screening resulted in 71 studies in mathematics and 104 in science that were included in the review, some with multiple parts and multiple publications.

The findings in these studies are generally quite positive. Studies involving interventions to deepen teachers' content knowledge, for instance, almost invariably find positive outcomes. In all likelihood, the group of studies in this review is biased, as publishing pressures (actual or perceived) may work against studies that find either no effect or negative effects.

Applying Standards of Evidence

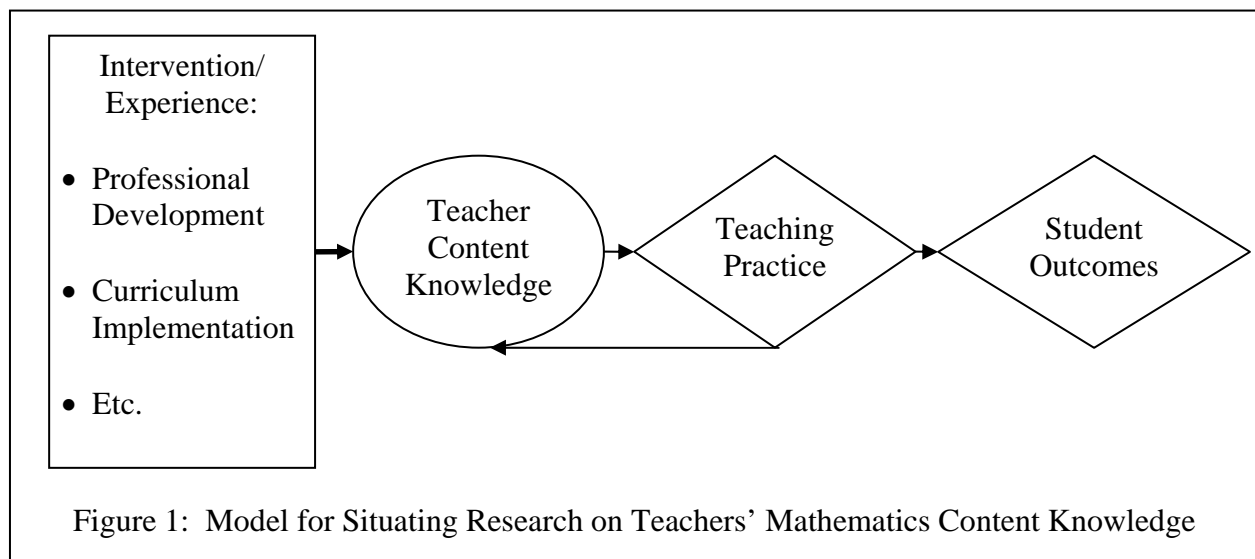
Each study was reviewed using a set of standards of evidence for empirical research. The KMD project developed the standards of evidence to operationalize principles for conducting empirical research in education and social science. The standards of evidence drew on numerous writings about research rigor, quality, and reporting, including efforts to address quantitative, qualitative, and mixed methodologies. A panel of mathematics and science education researchers, research methodologists, and mathematics and science education reform leaders assisted the KMD staff in the development of the standards of evidence to help ensure not only their quality, but also their broader utility.

The purpose of applying standards of evidence to the studies was to identify the contributions of each study to the field's knowledge base. Contributions were characterized in terms of what is known from the findings based on the substance of the study, and the confidence that can be placed in the findings based on the nature and quality of the study. Applying the standards of evidence was not intended to make "good/bad" or "in/out" judgments on studies, nor to suggest that all studies should be strong on every standard. Rather the application of standards of

evidence was conducted to aid understanding of the strengths and limitations of each study's contributions to the knowledge base.

Model for Situating Research on Teachers' Mathematics and Science Content Knowledge

The MSP-KMD team began the literature review process by developing a logic model for situating studies of teachers' mathematics and science content knowledge. The model was developed from the team's experience with evaluations of multiple teacher professional development and systemic reform projects in mathematics and science education. Figure 1 illustrates this model:



This model turned out to be a useful tool for categorizing the studies included in the review. Four categories were used to characterize the findings of the studies, with most studies falling into a single category:

- Studies of factors or interventions that contribute to or influence teachers' mathematics/science content knowledge;
- Studies of teaching practice as an influence on teachers' mathematics/science content knowledge;
- Studies of the influence of teachers' mathematics/science content knowledge on their teaching practice, including both classroom instruction and other aspects of teachers' professional work; and
- Studies of the relationship between teachers' mathematics/science content knowledge and outcomes for their students, primarily mathematics achievement.

Excerpts from the draft research review are included below. The first excerpt addresses what is known about interventions to deepen teacher content knowledge, and the second how MSPs stand to contribute to the empirical knowledge in this area, both focusing on mathematics. The next excerpt describes what is known about the relationship between teacher content knowledge

and classroom practice, followed by a discussion of the potential contribution of MSPs in this area, both focusing on science.

Sample Findings from the Empirical Knowledge Base: Experiences that Deepen Teachers' Mathematics Disciplinary Content Knowledge

Studies of the effects of six different professional development interventions on teachers' mathematics content knowledge were reviewed. All six of the programs were found to have a positive effect on measures of participating teachers' mathematics content knowledge. In all cases the professional development programs were fairly extensive, requiring at least several weeks of commitment; the teachers were indicated to be volunteers in nearly all cases. In at least one case (Sowder, Phillip, Armstrong, & Schappelle, 1998) the teachers were also carefully screened prior to selection for the intervention. Generalizability of the findings from these studies must be considered in light of these parameters, because the populations that these teachers represent are limited to teachers willing and able to commit to participation in such extensive interventions.

In most of the studies, the professional development intervention was described in some detail, which is helpful for understanding teachers' experiences and interpreting the link between the professional development interventions and the effects on teachers' mathematics content knowledge. In two cases, however, (Basista & Mathews, 2002; Clark & Schorr, 2000), the intervention was described in too little detail to support these interpretations. Adequate description of analysis procedures was also lacking in one study (Clark & Schorr, 2000). In another study (Garner-Gilchrist, 1993), results of the measures of teacher content knowledge were not directly reported, so the validity of claims regarding impact on teachers' content knowledge was not supported by the evidence presented.

It is important to recognize that particular features of the professional development programs, although described in detail and logically tied to some of the outcomes, were not studied through any systematic or naturalistic variation. Findings in these studies can only be understood to result from teachers' experience of the programs as a whole. Claims that particular features are important for deepening teachers' mathematics content knowledge, such as a focus on specific content ideas and students thinking about those ideas, are suggested to some extent by their presence in the multiple programs studied. However, the importance of particular features cannot be concluded from these studies.

An important consideration for several of the studies was the prevalence of the interventions being delivered by the developers and investigators (Sowder et al., 1998; Swafford, Jones, Thornton, Stump, & Miller, 1997; Swafford, Jones, & Thornton, 1999). On the positive side, this situation likely ensures that the programs were described and delivered as they were designed and intended. However, the implementation of the programs may have included facets that remained implicit and would therefore not appear in descriptions. Also, replication of the interventions as delivered by the developers would be very difficult.

Although all of these studies used either a pre-post design to measure changes in teachers' content knowledge or traced changes over time, none of the studies used comparison groups of

teachers who did not participate in the professional development programs. Given the experience levels of many of the participating teachers, the extent of professional development provided, and the nature of the measured changes, it is certainly reasonable to argue that the changes resulted from the interventions in other studies, but without comparisons to other teachers these claims are not solidly grounded. For example, it is possible that the teachers might perform better on a measure of content knowledge on a post-test simply because they had completed it previously, in one case (Basista & Mathews, 2002) only a few weeks apart. The use of multiple measures addresses this concern to some extent, as in the Swafford and colleagues (1997, 1999) study in which the participating teachers performed better in three different content areas, and on three separate measures of knowledge of geometry, following treatment, and in the Sowder and colleagues (1998) study, which used written instruments and interviews with teachers.

Contributions of MSP-Supported Research to the Empirical Knowledge Base

Contributions from MSP-supported studies regarding the effects of teachers' professional learning experiences on their mathematics content knowledge will come from a number of partnerships. Typically arising from evaluations of the impact of the partnerships' professional development programs, these studies are varied in terms of: (1) the grade levels of the participating teachers and the contexts in which they work, (2) the nature of the professional development programs, and (3) the measures of teachers' mathematics content knowledge.

Several studies involving pre- and post-professional development testing stand to contribute to the empirical knowledge base about the effectiveness of professional development programs in deepening teachers' content knowledge. Contributions of these studies potentially include detailed descriptions of the professional development programs, quantitative results indicating the extent and distribution of effects on teachers' mathematics content knowledge, and detailed illustrations of effects on teachers' knowledge.

The MSPs conducting these studies include partnerships serving elementary teachers (Preparing Virginia's Mathematics Specialists, Bill Haver, PI); middle grades teachers (Math in the Middle, Jim Lewis, PI; Standards-Mapped Graduate Education and Mentoring, Heinz-Otto Peitgen, PI), high school grades teachers (Rice University Mathematics Leadership Institute, John Polking, PI; Project Pathways, Marilyn Carlson, PI), and teachers across levels (Focus on Mathematics, Glenn Stevens, PI; Oregon Mathematics Leadership Institute, Thomas Dick, PI; Promoting Reflective Inquiry in Mathematics Education, James Parry, PI; Vermont Mathematics Partnership, Ken Gross, PI; Mathematical ACTS, Richard Cardullo, PI; Puerto Rico Math and Science Partnership, Josefina Arce, PI; El Paso Math and Science Partnership, Susana Navarro, PI). Several of these partnerships are specifically working to develop content knowledge among teacher leaders as well. The collection of studies for teachers from different grade levels and for teacher leaders will substantially augment the empirical knowledge base regarding the effects of professional development on teachers' mathematics content knowledge.

Another important contribution of MSPs' research is the development of additional detailed illustrations of changes in teachers' content knowledge as a result of their professional development experiences. For example, the Focus on Mathematics (Glenn Stevens, PI)

partnership has completed an interview study of seven participating teachers and is conducting more detailed case studies of six teachers. These studies will detail the teachers' experiences with the professional development program and the effects on their mathematics content knowledge. An important contribution of these studies will be illustration of gains in teachers' content knowledge arising from professional development aligned with the advanced knowledge perspective.

Another important contribution to the knowledge base that MSP-supported research studies are designed to make is examination of sustained impacts on teachers' mathematics content knowledge. For example, the Standards-Mapped Graduate Education and Mentoring project (Heinz-Otto Peitgen, PI) has planned follow-up data collection on participants in its professional development program to examine the nature and extent of sustained changes among teachers, including their mathematics content knowledge.

Several of the MSPs are assessing teachers' content knowledge gains using measures that are being developed through the work of the Measures of Content for Teaching Mathematics project (Heather Hill, PI) at the University of Michigan. These and other studies using these measures will feed into a meta-analysis planned by that RETA project. Combining results from several studies will allow the meta-analysis to estimate overall effects of multiple professional development programs on teachers' mathematics content knowledge, and possibly to identify particular features of professional development that influence gains in teachers' knowledge.

The meta-analysis will build on an existing study conducted by Hill and Ball (2004) in work related to their RETA project. In this study, the researchers found that the California Professional Development Institutes in mathematics had a significant positive effect on teachers' mathematics content knowledge as measured by early versions of the project's instruments for assessing mathematics content knowledge for teaching. Additionally, the variations in pre- to post-professional development gains, and differences in the structures of the institutes that were included, permitted investigation of the impact of professional development features on teachers' mathematics content knowledge. These analyses suggested that summer institutes of greater duration, and those that focused on mathematical analysis, reasoning, and communication had larger impacts on teachers' mathematics content knowledge. The researchers advised caution with respect to these results due to the fact that approximately one-fourth of the eligible institutes agreed to participation in the study, so biases in the samples of professional development experiences and teachers could have affected the findings.

Other MSPs are conducting their studies using different measures of teacher content knowledge. One possible contribution of these efforts is the validation and dissemination of these measures. For example, Project Pathways (Marilyn Carlson, PI) employs an instrument that has been used in research on students' and teachers' knowledge of pre-Calculus and Calculus to evaluate the impact of its professional development. The data collected in this study will afford further knowledge of the properties and usefulness of this instrument.

Sample Findings from the Empirical Knowledge Base: Teachers' Science Content Knowledge and Teaching Practice

This group of studies stands apart from others in the review in two ways. First, the consistency of findings is striking. Knowledge, whether disciplinary or about the nature of science, appears to exert strong influence on classroom practice. Second, these studies are among the most methodologically sound, although in many cases involve only small samples of teachers.

In terms of disciplinary content knowledge, these studies suggest that teachers with more content knowledge are more likely to teach in ways that help students construct knowledge. Two studies (Alonzo, 2002; Sanders, Borko, & Lockard, 1993) found that teachers pose more questions, and are more likely to have students consider alternative explanations, propose more investigations, and pursue unanticipated inquiries when they have strong content knowledge. The studies also found that teachers with weaker content knowledge tended to do more telling. Gess-Newsome and Lederman (1995) found that the way teachers organize their own knowledge affected how they then taught content. Similarly, Sanders et al (1993) suggest that teachers with weak content knowledge struggled to plan instruction that developed a conceptual storyline, in contrast to teachers with strong content knowledge.

With regard to the nature of science, Lederman's study (1999) found that when teachers have an established view of the nature of science, regardless of the view, they tend to translate that view into classroom instruction. That is, their instruction portrays an image of science consistent with their own view. This finding was common across all four studies dealing with the nature of science. Both Brickhouse (1990) and Cunningham (1998) found that teachers who saw science primarily as generative tended to do more inquiry type activities so students could generate knowledge. Those who saw science as a body of knowledge to be used to solve problems generally planned instruction so students used science in this way. Roehrig and Luft (2004) found this mirroring to be true even among the 14 first year teachers they studied, in contrast to Brickhouse (1990) and Lederman (1999), whose studies could not establish such a firm relationship in inexperienced teachers.

What is missing from these studies about the nature of science is attention to elementary science instruction. Of the seven studies, only one dealt with teachers in elementary schools. The reason for this disparity is not clear. In contrast, the majority of investigations on deepening teacher content knowledge identified for this review were situated in elementary instruction. Perhaps these studies were responding to well-documented weaknesses in elementary teachers' science knowledge. No such explanation is clear for the emphasis on secondary grades in studies of the relationship between content knowledge and classroom practice.

As a group, these seven studies are among the strongest in the review, primarily due to the wealth of data they collected and the extent of triangulation among data sources. All the studies dealt with small sample sizes, none more than 14 and most 5 or fewer. Perhaps the dependent variable—classroom practice—dictates small sample sizes. The data collection methods, which typically involve classroom observation, are quite time consuming and logistically complicated.

What the studies lack in sample size, they compensate for in the amount and kinds of data collected. Gess-Newsome and Lederman (1995) conducted 15 observations of each of the five teachers in their study. Brickhouse (1990) observed three teachers for a minimum of 35 hours each. In addition, all the studies collected other data, including interviews, questionnaires, and classroom artifacts (e.g., lesson plans and student work).

While the studies make it clear that findings are based on multiple data sources, it is not always clear how the data were combined and analyzed. Several studies were lacking in such description (Alonzo, 2002; Brickhouse, 1990; Lederman, 1999; Sanders et al., 1993). If the findings were not so consistent across studies, the lack of analysis detail would cast more doubt on the conclusions. A similar argument can be made for the potential weakness of small sample size, which threatens generalizability. Again, the findings are so consistent across settings to suggest that they are in fact generalizable.

Contributions of MSP-Supported Research to the Empirical Knowledge Base

Several MSPs stand to contribute to what is known about the relationship between teachers' content knowledge and classroom practice. Of the six MSPs involved in this type of research, one is a research, evaluation, and technical assistance (RETA) project that is focused on instrument development. The Assessing Teacher Learning about Science Teaching RETA (Sean Smith, PI) is developing a suite of instruments that include teacher assessments, student assessments, teacher opportunity to learn and student opportunity to learn. The project's research is focused on validating both assessments and the teacher and student opportunity to learn instruments. This research has the potential to provide evidence about the links between professional development, teacher knowledge, classroom practices, and student learning.

The El Paso MSP (Susana Navarro, PI) is a comprehensive partnership conducting two studies that stand to contribute to what is known about the relationship between teacher content knowledge and classroom practice. One of the planned interventions for this MSP has been the development of two new MAT degree programs in science, one in physical science and one in life science. The MSP plans to gauge the impact of the new MAT program in terms of changes in the graduates of the program with regard to their content knowledge, their pedagogical content knowledge, and resulting changes in their classroom practice. Classroom observations will be conducted at the beginning and end of the degree program.

The Teachers and Scientists Collaborating partnership (Gary Ybarra, PI), a targeted partnership working with K–8 teachers, is studying the relationship between TCK and classroom practice using classroom observations.

The St. Louis Inner Ring Cooperative (Edward Macias, PI) is also a targeted partnership working with K–8 teachers. The Cooperative is working to improve teacher's pedagogical content knowledge. As part of their work, they are using the Reformed Teaching Observation Protocol as the rating instrument for classroom observations. Although the focus of this MSP is more on the relationship between teachers' pedagogical content knowledge and student achievement, they are collecting classroom data that could contribute to the existing knowledge base about the relationship between teachers' content knowledge and teaching.

Practice-Based Insights

The MSP KMD project has used two main strategies thus far to gather practice-based insights in the area of deepening teacher content knowledge. The first was interviews with PIs of a sample of the NSF-supported MSP projects. The second was an on-line panel discussion with a group of people who had extensive and varied experience in professional development design and implementation.

Interviews with MSP PIs

MSP project staff interviewed the PIs of 27 MSP projects, including RETAs, comprehensive, targeted, and institute partnerships. Prior to these interviews, MSP KMD project staff reviewed project documents to get a sense of each project's context, and its goals and strategies related to deepening (or in the case of the RETAs, assessing) teacher content knowledge; the interviews then focused on gathering "lessons learned" as they had gone about their work. Some of the lessons identified by MSP PIs are described below.

1. Teacher content knowledge is much weaker than anticipated.

Even though most PIs went into the work knowing that they would be dealing with teachers who lacked a strong background in mathematics or science, many expressed surprise at just how serious this problem is. This realization sometimes arose from the particular context in which the project played out, and sometimes had implications for the PD that was provided. One PI pointed out that content knowledge in mathematics tends to vary, with teachers showing a deeper understanding of some concepts than others. A few examples are illustrative:

- Some projects that intended to focus their PD around specific curricula or science kits discovered that teachers were struggling with the content, so adjusted their PD to spend more time on content knowledge. Said one PI, "When we started offering professional development, we saw that the teachers did not know (for instance) what velocity and mass were. These are very basic principles that would be learned in a fundamental science course. Or worse, they were taught erroneously. So we had to start from scratch."
- One PI had worked with high school teachers previously, but in his middle school MSP, discovered that middle school teachers did not have as strong a content background as high school teachers.
- One PI noted that teachers' depth of knowledge in geometry is not very good, compared to their knowledge related to number and operations.
- The PI of a middle school science project was "alarmed" at teachers' weak content knowledge. The project administers multiple-choice "content surveys" in several areas to teachers when they enter the program. Teachers answered 20-30% of the items

correctly. Given that it is a multiple-choice instrument, the PI concluded that the teachers “statistically know nothing” about these science topics.

- One project was surprised that teachers identified to take leadership positions had very weak content knowledge.

2. Teachers respond positively to opportunities to delve into the content.

Even though there may be some initial resistance to content-focused PD, PIs of at least three projects noted that teachers respond very positively to opportunities to delve into the content, although one PI cautioned that a balance must be maintained between challenging teachers and keeping them engaged:

- The PI of a mathematics project reported that when early school-based study groups focused around pedagogy—which is what the administration requested they do—teacher attendance was low. Once they started getting into the mathematics, participation increased: “...when the mathematicians go into the schools and start talking to the teachers about mathematics the reaction is pretty uniformly that teachers really get into it. They like it, they know it’s important. It’s what they really want, it’s what they know they need.”

The PI of another mathematics project noted that their courses were demanding, and that the expectations for participants were high. Teachers responded by doing high-quality work, far beyond what project leaders had seen in other PD efforts.

3. Content-focused PD should integrate disciplinary and pedagogical content knowledge.

MSP projects used many kinds of PD designs, but a feature common to many was the integration of disciplinary and pedagogical content knowledge. There was a strong belief that these two aspects of teacher content knowledge should not be separated, and that concepts are best taught in the context of pedagogical practices that aid in understanding those concepts. A common view was that teachers must have not only disciplinary content knowledge, but understand where that knowledge is situated in the curricular trajectory, how students develop understandings, and common student misconceptions. PD must, therefore, address all of these things in an integrated fashion. As one PI stated, “...the premise of our work is that you have to have the content knowledge and then by coupling that with pedagogical practices, then you can become effective.” Another PI described her project’s PD as “content-based...wrapped up in everything we know about good instruction.” A few examples are illustrative:

- One project created graduate courses designed jointly by university faculty and master teachers; courses that addressed both content and pedagogy.
- Several science projects developed teachers’ content knowledge through the use of inquiry-based practices.

- A mathematics project offered problem-based courses that focused teachers' attention on "habits of mind" in mathematics; i.e., ways of doing and thinking about mathematics (process and content). The idea is that both disciplinary and pedagogical content knowledge would increase.
- Another mathematics project used "high-level discourse" as the "vehicle for folks to have an opportunity to grow mathematically." The idea is that disciplinary content knowledge is built through a particular pedagogy—discourse.
- A mathematics/science project used "explanation structures" to teach content, as explained by the PI: "We're definitely emphasizing content knowledge, but we're doing it in a new way through these things we're calling explanation structures for teachers. "... if you're going to talk about content knowledge, it's more than just content. It's the threads, the conceptual threads that go through the discipline."
- One project addressed pedagogical content knowledge explicitly by administering to participants Deborah Ball's/Heather Hill's Math Pedagogical Content Knowledge Assessment, which teachers reported provided an excellent PD experience in its own right.

4. Content-focused PD will be more meaningful to teachers if it is tied what they are doing in their own classrooms.

Several PIs mentioned that the PD they offered to teachers centered around realities that the teachers are experiencing every day. Some projects focused the PD around the actual curriculum teachers were using, teaching content within the context of those curricula. Others used student work or individual student assessment to identify student misunderstandings and then delve more deeply into the concepts and content. Another approach was to focus on the "curriculum trajectory" in the discipline; that is, the way ideas grow and build on each other in mathematics and science:

- Several projects use student work to identify student misunderstandings and help teachers confront their own lack of content knowledge.
- Numerous projects focused their PD around the specific curricula districts were using—such as Everyday Math, and algebra and geometry courses at the high school level. The curricula served as the vehicle for helping teachers build the content knowledge they needed to effectively implement the curricula.
- One project taught science content and pedagogy to teachers using "kitchen sink experiments" rather than college-level labs. These labs use everyday materials that are available in supermarkets or hardware stores to have students explore science concepts. Presenters have found that this approach enables them to push on the content at a high level while presenting labs that are easy enough and manageable enough for use with middle school students.

5. Even with a focus on curricula and student work, it can be a challenge to help teachers transfer their new knowledge to classroom practice.

A few PIs noted the difficulty of getting transfer to classroom practice, even when PD seems to have been well-received, and focused on teacher realities. The PI of a project that used topic-specific work based on materials from the classroom found in visiting schools that classroom change was slow. Another PI reported that teachers seemed to have been developing their content knowledge, but that project leaders “don’t know for sure how to help teachers transfer this [personal transformation] to student learning.” PIs of a third project expressed frustration that classroom practice was not changing more deeply. They conjectured that having teachers “discover those phenomena or relationships on their own in the same way we want students to do is probably not the most efficient” PD strategy. They were coming to the conclusion that there needed to be more “direct instruction” that would help participants understand how to translate these activities into learning experiences for their students.

Practitioner Panel

The second data collection strategy was an on-line “practitioner panel.” Fifteen people representing diverse backgrounds, different perspectives on what kinds of knowledge are most important for teachers, and varying kinds of experience in providing professional development to teachers of mathematics and science, were selected to participate in an on-line discussion. The panel was asked to respond to multiple rounds of questions about professional development practices intended to deepen teachers’ content knowledge. They did not know the identities of the other panelists, nor did they see their individual responses. Rather, project staff analyzed each round of data and reflected back some of the data to the panel for clarification and extension in the next round.

For example, quite a few of the panelists had experience in using student work to help teachers focus on student thinking in mathematics/science, and all of those indicated it was a potentially very effective strategy for this purpose. However, some described examples where the samples of student work to be examined were brought in by the professional development provider, and others examples where the teachers provided samples of their own students’ work. We noted that difference, and asked the panel to reflect on what guidance they could provide to the field about the circumstances under which each was most appropriate. The consensus—including those who had not used student work in professional development, but were considering the two options on theoretical grounds—was that it was helpful to start with prepared samples. First, selecting examples in evidence would allow the professional development provider to ensure that they were rich enough so that teachers could infer the students’ thinking, and that as a group, the examples represented a range of possible student responses. Second, in analyzing work from “other” teachers’ students, teachers would be less likely to feel defensive about the fact that students did not appear to understand ideas that had been addressed in class. Once teachers were comfortable with the process of analyzing student work, and saw how helpful it was in giving them a window into student thinking and identifying areas in need of further instruction, they could be asked to bring in samples of their own students’ work, thus facilitating the application of their newly developed skill to their own practice.

The panel data detailed this group of practitioners' knowledge about each of a number of professional development practices in relation to achieving particular purposes; and what appears more or less effective, as well as their conceptions of what kind of teacher content knowledge is being deepened in each case. The following examples illustrate the kinds of knowledge gleaned from the practitioner panel.

Engage teachers in the development of a conceptual map of the content as a vehicle for deepening their content knowledge

Panelists noted that when teachers worked to develop a conceptual map of a “big idea,” showing connections among the various sub-ideas, they deepened their understanding of mathematics/science content.

I think deep understanding is actually defined by having rich mental connections about a concept. So, if I understand something in multiple ways, if I can give a variety of examples (and non-examples) of a concept, if I can explain applications of the concept, if I can talk about simpler and more complex related concepts— then I really have good understanding. Sometimes making these connections explicit in professional development is helpful to teachers—and this may be done through concept mapping.

Descriptions of the process by which teachers develop concept maps highlight the opportunities for teachers to trace the relationships among ideas; compare maps with others, identifying common features; and surface and address misunderstandings. Sometimes teachers create concept maps that reflect their current understandings (and lacks of understanding), and that is the end of it. Panelists cautioned that unless teachers have opportunities to learn more about content and content connections in the process of developing concept maps, there is little point in the enterprise.

Deepening teacher content knowledge through the analysis of student instructional materials

One of the approaches sometimes used in professional development to help teachers deepen their content knowledge is to engage teachers in analyzing the mathematics/science content in their students' instructional materials. The perceived benefits of this approach are that (1) teachers will see the relevance of the professional development to their teaching; (2) the process will help teachers enhance their understanding of the content; and (3) the process will give teachers a clearer idea of how the various activities in the student materials are intended to develop student understanding.

One panelist described the effective use of the strategy in professional development as follows.

[Our process included] having teachers work through the instructional materials with a focus on the content developed in each activity, providing a structured tool within which to frame the content analysis, using the instructional activities analysis to raise questions about teachers' own understanding of the content of the unit, looking across the unit activities at the story line being developed and making modifications to clarify

and make that story line more coherent, using the inquiry standards to think about the level of cognitive demand in the activities and modifying or inventing other activities to raise the level of demand, identifying gaps in the materials and developing other activities to address those, and analyzing the instructional approach in the unit, comparing that to the research on science teaching and learning, and modifying/inventing the approach to make the unit more inquiry-oriented for children.

Panelists noted, however, that teachers would likely get the most benefit out of the process if the examination of the materials is structured in a way that focuses on the concepts and conceptual connections in the materials, not simply lists of topics. Said one:

[It is important] to provide a frame for teachers to examine the materials. There are many things to look at, and a need to move beyond the surface features. It is all about the focus, so we can get teachers to consider the mathematical ideas in relation to each other and consider the big or core mathematical ideas in the materials.

And while a tool for structured examination is likely to help, facilitators need to make sure to keep the focus on the concepts and conceptual connections throughout the process. Panel members agreed that there was a need to address both content and pedagogy at some point in the process of engaging teachers in analyzing student instructional materials. However, they had differing views on how to capitalize on teachers' interest in issues of classroom application, and address their questions in this area, without losing the focus on content. Some panelists suggested a "back door" approach to the content. For example,

I think this practice [analyzing student instructional materials] has worked for the purpose of deepening teachers' understandings, when the explicit reason for analyzing the content is to anticipate student thinking rather than to shore up the teachers' thinking. So - the question "What might a student say about this?" has been a nice entry into talking about subtleties in the content, better than "What's your answer?"

Others disagreed with the notion of a back door approach to the mathematics/science content, making the case that a direct focus on the content in the student materials would increase the likelihood that teachers would both learn the content themselves and focus on content when implementing those materials in their classrooms. In their view, facilitators should be upfront with teachers when the focus of the analysis of student materials is on increasing teacher content understanding, although care needs to be taken to create a safe environment for teachers to acknowledge their content needs. Said one panel member:

The purpose must be front and center—for any PD. If the purpose of looking at the materials is to develop content knowledge, facilitators must be explicit about that from the get go, identify what concepts those are and ensure the group moves in that direction. Making expectations clear and then periodically checking as to whether we are staying true to purpose is critical to actually achieving the desired outcomes.

Discussions about the need to focus on content rather than pedagogy led quite a few panel members to express discomfort with the idea that content and pedagogy are separable. Rather,

they preferred to think of these issues as intertwined, although one or the other might be in the foreground depending on the purpose at a particular point. Finally, panel members expressed some concerns about using this particular strategy for the purpose of deepening teacher content knowledge. One concern was that teachers need a deeper understanding of the content than do their students, so having teachers analyze student-level content will not be sufficient.

Analyzing the content in the instructional materials certainly can bring focus to the big ideas and ensure teachers are focusing on the content, not just the activities. This can be a good place to start, but teachers do need to understand the content with a greater level of sophistication than their students.

In addressing teacher content knowledge, pointing out content errors and clarifying potentially confusing statements may be sufficient, but teachers will also need to know how to address any inaccuracies that are identified in the materials, as well as gaps within and across grades. The fact that some student instructional materials are not well designed to develop conceptual understanding led one panelist to suggest that analysis of the content in student materials is not an efficient way to go about deepening teacher content knowledge.

I think the task, "analyzing the content of the students' instructional materials" is a good idea, but it should be, at best, a secondary goal to use this to deepen teachers' understanding of mathematics. If that's the goal, this is a very inefficient way to get it done. We had a "middle-level math" institute and the curriculum materials used in our teachers' classrooms, more often than not, did a poor job with the mathematics. This isn't the place to learn mathematics. It may be the place to learn that the teacher needs a deep understanding of the mathematics because the curriculum materials are unlikely to provide the help the teacher needs

Next Steps

The MSP KMD project is continuing the analysis of data from the PI interviews and practitioner panel. Once those analyses are completed, the practice-based insights will be arrayed against the findings from the empirical literature, both the studies identified in the literature search process and studies conducted by MSP projects as they become available. Ideas that are well-supported by both empirical evidence and practitioner insights will be prime candidates for knowledge sharing, so that the broader field can base their decisions on efforts to deepen teacher content knowledge on what is known. If there are empirical findings that were not explored on the practice-based side, we will attempt to fill those gaps through additional interviews and review of selected practitioner literature. Ideas that are supported by practice-based insights but that have not been adequately investigated empirically will be tagged as priorities for future research.

Reference List

- Alonzo, A.C. (2002). Evaluation of a Model for Supporting the Development of Elementary School Teachers' Science Content Knowledge. *Proceedings of the Annual International Conference of the Association for the Education of Teachers in Science (Charlotte, North Carolina, January 10-13, 2002)*.
- Askey, R. (Fall, 1999). Knowing and teaching elementary mathematics. *American Educator*, 1-8.
- Ball, D. L. & Bass, H. (2001). What mathematical knowledge is entailed in teaching children to reason mathematically? in Mathematical Sciences Education Board (Ed.), *Knowing and learning mathematics for teaching: Proceedings of a workshop* (pp. 26–34). Washington, DC: National Research Council.
- Ball, D. L., Hill, H. C., & Bass, H. (2005). Knowing Mathematics for Teaching: Who Knows Mathematics Well Enough To Teach Third Grade, and How Can We Decide? *American Educator*, Fall 2005, 14-23.
- Ball, D. L., Lubienski, S., & Mewborn, D. (2001). Research on teaching mathematics: The unsolved problem of teachers' mathematical knowledge. In V. Richardson (Ed.), *Handbook of Research on Teaching (4th ed.)*, 433-456. New York: Macmillan.
- Basista, B., & Mathews, S. (2002). Integrated Science and Mathematics Professional Development Programs. *School Science and Mathematics*, 102(7), 359-70.
- Begle, E. G. (1972). Teacher knowledge and student achievement in algebra (SMSG Report No. 9). Palo Alto, CA: Stanford University.
- Begle, E. G. (1979). *Critical variables in mathematics education: Findings from a survey of the empirical literature*. Washington, DC: Mathematical Association of America and National Council of Teachers of Mathematics.
- Brickhouse, N.W. (1990). Teachers' Beliefs about the Nature of Science and Their Relationship to Classroom Practice. *Journal of Teacher Education*, 41(3), 53-62.
- Choi, J. & Ahn, S. (2003). *Measuring teachers' subject-matter knowledge as a predictor of the quality of teaching*. Paper presented at the annual meetings of the American Educational Research Association, Chicago, IL, April 21-25, 2003.
- Clark, K. K., & Schorr R. Y. (2000). Teachers' evolving models of the underlying concepts of rational number. Paper presented at the annual meetings of the North American Chapter of the International Group for the Psychology of Mathematics Education, Hiroshima, Japan, July 23-27, 2000.
- Cunningham, C.M. (1998). The Effect of Teachers' Sociological Understanding of Science (SUS) on Curricular Innovation. *Research in Science Education*, 28(2), 243-57.

- Cuoco, A. (2001). Mathematics for teaching. *Notices of the American Mathematical Society*, 48(2), 168-174.
- Dewey, J. (1897). The psychological aspect of the school curriculum. *Educational Review*, April, 356-369.
- Garner-Gilchrist, C. (1993). Mathematics institute: An inservice program for training elementary school teachers. *Action in Teacher Education*, XV(3), 56-60.
- Gess-Newsome, J. and Lederman, N. G. (1999). (Eds.), *Examining Pedagogical Content Knowledge* (pp. 133-144). Kluwer: The Netherlands.
- Gess-Newsome, J., & Lederman, N.G. (1995). Biology Teachers' Perceptions of Subject Matter Structure and Its Relationship to Classroom Practice. *Journal of Research in Science Teaching*, 32(3), 301-25.
- Hill, H. C. & Ball, D. L. (2004). Learning mathematics for teaching: Results from California's Mathematics Professional Development Institutes. *Journal for Research in Mathematics Education*, 35(5), 330-351.
- Lederman, N.G. (1999). Teachers' Understanding of the Nature of Science and Classroom Practice: Factors That Facilitate or Impede the Relationship. *Journal of Research in Science Teaching*, 36(8), 916-29.
- Ma, L. (1999). *Knowing and teaching elementary mathematics : teachers' understanding of fundamental mathematics in China and the United States*. Mahwah, N.J.: Lawrence Erlbaum Associates.
- Monk, D. (1994). Subject area preparation of secondary mathematics and science teachers and student achievement. *Economics of Education Review*, 13(2), 125-145.
- Nevis, E.C., DiBella, A.J., & Gould, J.M. (1995). Understanding organizations as learning systems. *Sloan Management Review*, 36(2), 73-86.
- Roehrig, G., & Luft, J. (2004). Constraints Experienced by Beginning Secondary Science Teachers in Implementing Scientific Inquiry Lessons. Research Report. *International Journal of Science Education*, 26(1), 3-24.
- Sanders, L.R., Borko, H., & Lockard, J.D. (1993). Secondary Science Teachers' Knowledge Base When Teaching Science Courses in and out of Their Area of Certification. *Journal of Research in Science Teaching*, 30(7), 723-36.
- Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 8-9.
- Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1-22

- Sowder, J. T., Phillip, R. A., Armstrong, B. E., & Schappelle, B. P. (1998). *Middle-grade teachers' mathematical knowledge and its relationship to instruction*. Albany, NY: State University of New York Press.
- Swafford, J. O., Jones, G. A., Thornton, C. A., Stump, S. L., & Miller, D. R. (1999). The impact on instructional practice of a teacher change model. *Journal of Research and Development in Education*, 32(2), 69-82.
- Swafford, J. O.; Jones, G. A., & Thornton, C. A. (1997). Increased knowledge in geometry and instructional practice. *Journal for Research in Mathematics Education*, 28(4), 467-83.
- Wu, H. (1997). On the education of mathematics teachers. Retrieved February 21, 2006 from <<http://math.berkeley.edu/~wu/teacher-education.pdf>>.

