Designing for Sustainability: Lessons Learned About Deepening Teacher Content Knowledge from Four Cases in NSF's Math and Science Partnership Program

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Iris R. Weiss
Daniel J. Heck
Joan D. Pasley
Evelyn M. Gordon
Patricia J. Kannapel

Horizon Research, Inc.

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Introduction

The National Science Foundation's (NSF) Math and Science Partnership (MSP) program, established in 2002, involves science, technology, engineering, and mathematics (STEM) faculty from institutions of higher education in partnerships with K–12 districts to improve the quality of mathematics/science education and to add to the knowledge base for education reform more broadly. More than 100 partnership projects were funded between 2002 and 2010, with plans to support additional projects in the future.

The MSP Knowledge Management and Dissemination (MSP KMD) project is charged with synthesizing what the partnerships are learning in a number of key areas, and situating those lessons in the broader education improvement knowledge base. One of these focus areas is ***deepening teacher content knowledge***, which has been of particular interest to the MSP KMD work for three reasons. First, research on mathematics and science teaching over the past 25 years has provided a growing body of evidence that teachers' knowledge of the content they teach is positively related to the nature and quality of their instruction and to their students' learning (e.g., Fennema, Carpenter, Franke, Levi, Jacobs, & Empson, 1996; Gess-Newsome & Lederman, 1995; Henze, van Driel, & Verloop, 2008; Hill, Blunk, Charalambous, Lewis, Phelps, & Sleep, 2008; Ma, 1999; Sanders, Borko, & Lockard, 1993; Sowder, Phillip, Armstrong, & Schappelle, 1998). Second, over this same period, several large federal funding programs have supported teacher professional development specifically focused on improving teaching in K–12 mathematics and science, such as the Department of Education's Dwight D. Eisenhower Mathematics and Science Education Program, and the National Science Foundation's Systemic Initiatives Programs and Local Systemic Change through Teacher Enhancement Program (Banilower, Boyd, Pasley, & Weiss, 2006; Desimone, Porter, Garet, Yoon, & Birman, 2002; Zucker, Shields, Adelman, Corcoran, & Goertz, 1998). Third, the National Science Foundation's and Department of Education's Math and Science Partnership programs continue this trend in federal funding, with an explicit commitment to professional development that targets teachers' mathematics and science content knowledge in order to improve their students' learning through stronger instruction (U. S. Congress, 2002). Lessons learned about designing and implementing professional development to enhance teacher content knowledge can enable program leaders to be more strategic in their efforts, using resources more efficiently and addressing challenges more effectively.

In earlier work, the MSP KMD team developed the *Handbook for Enhancing Strategic Leadership in the Math and Science Partnerships* (Weiss, Miller, Heck, & Cress, 2004). The *Handbook*, which was based on prior research on large-scale reform, set forth some principles about leadership, decisions, and actions that contribute to sustainable reform; it was intended to help guide MSP leadership teams in their efforts to improve mathematics and science education.

As part of the current project, the MSP KMD team conducted a series of case studies of MSP projects, using the *Handbook* as a framework for understanding the work of these partnerships between school districts and institutions of higher education. A set of four project-specific case reports related to deepening teacher content knowledge were developed and can be found here. This report presents a cross-case analysis, based on the strategic leadership framework, that incorporates lessons learned from the MSPs. The case reports and the cross-case analysis are not

intended to evaluate the projects' progress in achieving their goals, but rather to focus attention on aspects of the projects' work that appeared to affect sustainability.

The report begins with an overview of the strategic leadership framework from the *Handbook*. It continues with a brief summary of each of the MSP cases of deepening teacher content knowledge to set the context for the lessons and examples from the cases that are shared in the remainder of the report.

Strategic Leadership for Sustained Large-Scale Reform

The MSP program emphasizes the need for projects to plan not only for substantial improvements in mathematics/science education in the partner districts, but also for sustainability of their efforts. For example, an early MSP program solicitation (and later ones as well) included the following guidelines:

> *To ensure project sustainability, K–20 core partner organizations redirect resources and design and implement new policies and practices to result in well documented, inclusive and coordinated institutional change at both the college/university and the local school district level. Higher education core partners reward faculty in mathematics, the sciences and/or engineering for strengthening their own teaching practices and for their work in K–20 mathematics and science education, including K–12 teacher preparation and professional development. K–12 core partner organizations create and sustain an environment that values an evidence-based approach and that recognizes and rewards significant contributions to improved mathematics and science learning and teaching.* (National Science Foundation, 2003)

MSP projects are typically awarded as five-year grants to reach a designated number of teachers, but they are expected to develop interventions that can be scaled up with quality and have an on-going impact on mathematics/science education well beyond the funded period. In the case of deepening teacher content knowledge, given the wide range of teacher needs, designing effective programs is quite challenging. Doing so with an eye toward scalability and sustainability is even more difficult, requiring leaders who are both very knowledgeable and highly strategic.

Strategic leadership starts with understanding the system one is trying to improve, and then being planful in changing the system toward greater coherence and alignment around the agreed-upon goals. In the *Handbook*, four inter-related components were identified as critical to implementing and sustaining reform in mathematics and science education.

Designing and implementing interventions is the part of the work that most people think about when they plan for reform. Planning for projects involves making decisions about the details of the interventions and, in the case of deepening teacher content knowledge, making the case that the planned professional development will be effective in addressing the needs of the teachers. Strategic leaders typically go further; these leaders describe how they will determine the extent to which the interventions are working and make mid-course corrections accordingly in an attempt to use available resources as strategically as possible.

The second component of program improvement is ***garnering support from key stakeholders***. Proposers can typically count on the support of the people who will be integrally involved in project activities, such as those designing or providing professional development. However, to be both effective and sustained, projects will likely need the support of a variety of other stakeholders as well, e.g., principals, superintendents, school boards, parents, and, in some cases, teacher unions. Often project plans include gaining support from district leaders, but do not typically provide much information about how the project will involve them. Recognizing the importance of this component of the work for sustainability of improvement efforts, strategic leaders develop plans for garnering the support of a variety of key stakeholders.

Effective and sustained improvement requires ***considering the policy environment*** as well. As noted in the *Handbook*, there is no shortage of education policy at both the state and district levels, and projects aimed at deepening teacher content knowledge in order to improve classroom practice need to be prepared to contend with much of it. Typically, states determine the mathematics and science content that should be addressed, as well as teacher certification and renewal requirements. Districts layer on additional policies, perhaps more detail about what content should be taught at particular grade levels, or what "counts" toward teacher certificate renewal. Often there are assessments administered at both the state and district levels, with various stakes attached for students, teachers, and/or schools. To varying extents, and at various times, these policies influence the actions of players throughout the system. Although it is difficult to imagine long-lasting reform if district curriculum, instruction, student assessment, teacher evaluation, and professional development policies are not aligned with the reform vision, project plans are often sketchy about this component of the work. Strategic leaders, in contrast, consider how existing policies will affect the implementation and sustainability of the planned reforms, how they can leverage supportive policies, how they can work around the policies that are likely to be problematic, and how they might work towards greater alignment of the policy environment with the project's vision.

The fourth component of reform addressed in the *Handbook* is ***scaling up***, e.g., providing professional development not just to a handful of mathematics/science teachers who volunteer to participate, but to large numbers of teachers in order to improve teaching and learning district-wide. In contrast to stakeholder support and policy issues, the problem is not that scaling up is ignored in project plans, but rather that the plans for scaling up tend to underestimate the challenges involved. A highly skilled and experienced core group of project leaders can often provide effective interventions themselves, but they will almost certainly need to bring in other, typically less experienced, people to reach the critical mass of participants for system-wide reform. Project leaders may describe plans to use teacher leaders in order to provide professional development for a large number of teachers in the partner districts, but often have not thought through these plans in detail, leaving it unclear how these teacher leaders will develop the skills or find the time and opportunity necessary to do this work. Strategic leaders recognize that meaningful system-wide reform requires investment in building capacity and infrastructure to scale up and sustain the improvement efforts.

Strategic leaders will have reform plans that address all of these components, although not necessarily all at once, and will look for ways to take advantage of activities in one arena to

make progress in others as well. For example, piloting an intervention can help not only in making sure it works smoothly, but also in developing the capacity of STEM faculty and teacher leaders beyond the core team so they will be in a better position to scale up the interventions with quality. Similarly, as the pilot interventions move forward, collecting data on their effectiveness in achieving important outcomes can help garner support from higher education and district stakeholders. Evidence of effectiveness and stakeholder support together can bolster efforts to align policy that will enhance sustainability.

Overview of the Case MSPs

Examples from the cases are used in later sections of this report to illustrate from the MSPs' experiences lessons learned about strategic leadership. The cases are briefly summarized below to aid the reader in understanding the contexts from which the examples have been drawn.

Consortium for Achievement in Mathematics and Science (CAMS) MSP
CAMS began in 2003 as a partnership among the Merck Institute for Science Education (MISE), Kean University, the Educational Testing Service (ETS), and the New Jersey public school districts of Elizabeth, Hillside, Linden, and Rahway. The CAMS partners, with the exception of ETS, are located in Union County, New Jersey where Merck & Co., Inc. has major facilities. The CAMS MSP built on ten years of prior work by MISE to support K–12 mathematics and science education reform in districts near Merck facilities.

The overall goal of the CAMS MSP was to enhance student learning in the partner districts by providing challenging, high quality mathematics and science instructional programs in middle grades classrooms. Objectives toward that goal included:

- Developing curriculum frameworks and selecting instructional materials;
- Developing capacity to provide content-focused professional development and support;
- Enhancing teacher content knowledge and skill through curriculum workshops;
- Supporting teachers through in-class coaching; and,
- Building capacity and support among administrators.

Although CAMS addressed both mathematics and science education, this case focuses on the project's efforts in science education. The program supported partner districts in selecting commercially available instructional materials aligned with state and local standards. It then offered curriculum workshops for teachers focused on these instructional materials, along with in-class support to implement those materials. CAMS involved district personnel in these efforts to develop capacity for sustaining the efforts beyond the funded period. Similarly, CAMS provided annual Administrator Institutes to develop the capacity of administrators to continue to support science education improvement.

Puerto Rico Math and Science Partnership (PR–MSP)
Launched in 2003, PR–MSP was a partnership between the Puerto Rico Department of Education (PRDE) and universities across the island. The PR–MSP built on a prior NSF grant

(the Puerto Rico Statewide Systemic Initiative), and included many of the same partners. The ambitious goal of PR–MSP was to transform mathematics and science learning K–12 and beyond. The hope was to eventually work with all mathematics and science teachers across the island, ultimately reaching all students. With this aim in mind, PR–MSP focused on:

- Developing a partnership between the university system and PRDE;
- Creating a regional support structure to ultimately reach all teachers and students across the island;
- Developing capacity to provide professional development and support;
- Deepening the disciplinary content knowledge and pedagogical content knowledge of K–12 mathematics and science teachers; and
- Developing supports for school-level change to support mathematics and science education reform.

The centerpiece of PR–MSP's work with K–12 teachers was a system of Resource Centers in each of 10 regions across the island. These sites served as centers for a professional development series attended by teachers from 155 participating elementary, middle, and high schools. In science (the focus of the case study), both the summer courses and academic-year sessions focused on specific science concepts for each grade level. Courses were expected to model effective instructional and assessment strategies to help teachers transfer their emerging content knowledge to the classroom. PR–MSP also worked to establish school-based learning communities to support classroom implementation of science education reforms, as well as occasional "communities of practice" in which project staff and teachers identified and explored more deeply particular concepts or issues of practice. The MSP KMD case study focuses on PR–MSP's work in science at the elementary level.

System-Wide Change for All Learners and Educators (SCALE) in Los Angeles

SCALE began in 2003. Addressing both mathematics and science education improvement, SCALE was a partnership between the University of Wisconsin's Center for Education Research and four urban school districts across the country: Los Angeles Unified School District (LAUSD), Madison Metropolitan School District, Denver Public Schools, and Providence Public School District. Local higher education institutions served as partners at each of the sites. The MSP KMD case study focuses on the work around middle school science in the Los Angeles school district.

SCALE's efforts in Los Angeles involved the University of Wisconsin, LAUSD, California State University Dominguez Hills, and California State University Northridge. SCALE sought to change science instruction from a textbook-based approach to an instructional program that would take students deeply into the conceptual core of science. The centerpiece of the work at the middle grades was a set of science immersion units, with professional development provided to teachers to facilitate their implementation of the units. The immersion units were intended to provide a coherent series of lessons to guide students in developing deep understanding of fundamental science concepts included in state standards, incorporating essential features of classroom inquiry. The immersion unit design team consisted of University of Wisconsin project leaders, faculty at the California State universities, and LAUSD district staff developed the units.

A professional development study group with a similar composition designed professional development to support teachers in implementing the units.

Texas Middle and Secondary Mathematics Project MSP (TxMSMP)
Begun in 2002, TxMSMP was a partnership between Stephen F. Austin State University (SFASU) and 12 rural independent school districts in East Texas. Other institutions of higher education, including both universities and community colleges within Texas, served as supporting partners. The overarching mission of the TxMSMP was to improve the mathematics learning experiences and achievement of middle and secondary grade students. The vehicle that was chosen for this purpose was content-focused graduate programs to upgrade the knowledge and skills of under-qualified in-service teachers of mathematics at these grade levels.

The goals of the TxMSMP grant were to deepen teachers' understanding of targeted core mathematical ideas; why that knowledge was important for their mathematics teaching; and how that knowledge applied to their mathematics instruction, with the ultimate purpose of improved student performance in mathematics. Three primary intervention strategies planned for meeting these goals were:

- Graduate degree programs for teachers consisting of a series of mathematics courses, leadership and mentoring courses, projects, portfolios, and exams;
- Mentoring of teachers by university mathematics faculty; and
- Teacher involvement in summer mathematics enrichment opportunities for middle- and high-school students in their respective school districts.

The programs were designed to serve 60 middle-level mathematics teachers (two cohorts of 30 teachers) and 30 secondary-level mathematics teachers (one cohort), with the idea that the teachers who completed the programs could provide mathematics leadership back in their school districts. In each participating district, a coordinator was identified to work with the project by nominating and recruiting candidates for the degree programs.

The four case MSPs had somewhat different foci in their efforts to deepen teacher content knowledge. CAMS and SCALE centered their work on modules/units that would deepen students' conceptual understanding; professional development for teachers was central to this work to ensure that teachers understood the concepts and could teach them effectively. The Puerto Rico MSP also focused on deepening teacher understanding of essential science concepts, but in a more general way; the professional development did not focus on specific instructional materials. TxMSMP differed from the other three cases in that it involved graduate programs for teachers, providing much more intensive treatment than was possible in a professional development program.

CAMS and TxMSMP were smaller in scope than were SCALE and PR–MSP. CAMS focused on four school districts, two of which had prior relationships with MISE, the lead agency for the MSP. TxMSMP targeted 90 teachers for graduate coursework. In contrast, the PR–MSP worked

with a large number of teachers from 155 schools across Puerto Rico, including teachers from the entire K–12 spectrum; and SCALE worked with teachers in a district of 700,000 students, many of them English language learners and from low-income families. The different contexts and challenges of these case MSPs are considered below in discussing lessons learned from their experiences.

Analytic Process

The bulk of data collection for the MSP case studies was conducted during the 2007-08 school year, with follow-up data collection continuing through 2010. Data collection occurred near the end of the grant period in each MSP in order to get information on both the evolution of the efforts and on project leaders' strategies for sustaining the work beyond the grant period.

Data collection included reviews of proposals, annual reports, and other project documents; observations of project activities; and interviews with individuals identified by MSP Principal Investigators. Interviews were conducted with university STEM faculty and education faculty, professional development designers and providers, district administrators, school principals, teacher leaders, and teachers. A multiple-day site visit was made to each case MSP by a two-person research team, during which interviews were conducted and project activities were observed.

Analytic memos were drafted that combined data from the interviews with data gleaned from project documents. These memos were framed around the four components of reform highlighted in the *Handbook* on strategic leadership. The memos were reviewed by both researchers who visited each site and revised based on communications within the research team. The four cases were developed from the analytic memos, then reviewed and revised by members of the research team. The Principal Investigator of each case MSP had an opportunity to review and provide input on the draft case.

Cross-case analysis began with a meeting of MSP KMD staff, including research team members who had visited the sites and written the case reports. Data from each case were analyzed in light of the components from the *Handbook*. During the course of this analysis, six major lessons learned across the case MSPs emerged. The lessons identified are used as the overall organizer for this report. Selected examples from MSPs are clustered under a small set of key ideas that operationalize each lesson. Both the individual case reports and the cross-case analysis were reviewed by the Principal Investigators of the case MSPs prior to publication, in order to check for accuracy. In addition, the results of the cross-case analysis were reviewed by MSP KMD staff who did not participate in data collection or analysis.

Lessons from the MSPs

As noted earlier, the framework introduced in the *Handbook for Enhancing Strategic Leadership in the Math and Science Partnerships* (Weiss et al., 2004) informed data collection and analysis

for this study. The information gathered helped to flesh out some of the ideas in that framework, and to revise others, reflecting the experiences of the case MSPs.

To increase the likelihood of meaningful, sustained improvement, the data suggest, leaders of initiatives designed to deepen teacher content knowledge need to:

1. Recognize that it takes time to develop and nurture a *productive partnership*.
2. Consider how to *engage a range of important stakeholders whose support is important* for efforts to deepen teacher content knowledge.
3. Help ensure that *key policies in the system are aligned with the vision* underlying the reform efforts.
4. Design and implement professional development that is not only aligned with the project goals, but is also both feasible and *likely to be effective with the teachers in their particular context*.
5. *Use data* to inform decisions, improve the quality of the interventions, and provide evidence to encourage support for system change.
6. Work to *develop capacity and infrastructure* to strengthen teachers' content knowledge and pedagogical skills, both during the funded period and beyond.

Each of these lessons is broken down into a number of key ideas that are illustrated using examples from one or more of the case MSPs. Examples were selected for their illustrative qualities; for some key ideas additional examples are evident in the project-specific case reports but have been omitted in the cross-case analysis for brevity.

The goal in examining the lessons learned from the case MSPs is not to prescribe how to design and implement mathematics and science education reform. Leaders of the case MSPs would be the first to acknowledge that their efforts were not uniformly successful, and that, in hindsight, there is much that they would have done differently. Moreover, given that education reform efforts are enacted within diverse and complex systems, it is unlikely that a set of interventions that was well-received and effective in one of these MSPs, or in any other particular setting, would be equally appropriate and helpful in another context. Rather, the goal is to suggest how leaders of future efforts *can think about* designing and implementing mathematics and science education reform in order to increase the likelihood of producing lasting change in the contexts in which they work.

Planning and implementing complex initiatives requires a myriad of decisions, both large and small. Project leaders should expect to make many decisions that involve trade-offs as they confront obstacles and consider the advantages and disadvantages of alternative courses of action. The examples described in this report illustrate how different MSPs made decisions, explicitly or implicitly negotiating the various trade-offs, as they sought to achieve their teacher content knowledge goals during their projects and to ensure sustained impact in the future. The hope is that reading about the rationales for their activities and the consequences of their decisions will help future reform leaders in considering strategic decisions in their particular contexts.

Lesson 1: Recognize that it takes time to develop and nurture a productive partnership. MSPs, by definition, had to include at least one school district and at least one institution of higher education. As noted in the *Handbook* on strategic leadership, the kind of partnership envisioned by NSF involves far more than a small group of highly committed individuals preparing a proposal and carrying out MSP activities. Instead, effective partnerships need to be "strategic alliances," in which the partner organizations form a coalition to achieve shared goals and collaborate on a long-term agenda.

A critical ingredient for true partnerships is ensuring that each of the collaborating organizations perceives the partnership as beneficial for their institution. For instance, K–12 educators may appreciate the fact that a partnership with a college or university will provide access to mathematics and science expertise that can be used for teacher professional development and improving course content and pedagogy. Institutions of higher education may recognize that partnering with K–12 school districts provides an opportunity to improve mathematics and science instruction for undergraduates and children of faculty members, to enhance the preparation of prospective teachers through practicum experiences, and to improve the quality of mathematics and science teaching at the university level.

Even when all parties anticipate that a partnership will be beneficial, project leaders must recognize that bringing together institutions from different sectors of society may produce a "culture clash." It takes on-going effort to identify common ground, develop a shared vision, and sustain mutual commitment to the reform process. The MSPs' focus on teacher content knowledge provided an effective vehicle for developing shared goals, because deepening teacher content knowledge requires the expertise of both disciplinary specialists and people who understand the realities of K–12 classroom practice. MSPs typically created partnerships that included university disciplinary experts, university teacher education faculty, and district practitioners.

Analysis of the MSP cases surfaced three key ideas about the development of productive partnerships to enhance teacher content knowledge during the project and to sustain the improvement process beyond the funded period.

Key ideas for developing and nurturing productive partnerships

Ensure the partnership includes as core partners all of the institutions whose involvement will be crucial during and/or after the funded period.

Involve leaders from the core partners in the work in order to nurture the partnership.

Attend to the needs of K–12 mathematics/science education as perceived by core partners.

Key idea: Ensure the partnership includes as core partners all of the institutions whose involvement will be crucial during and/or after the funded period.

It is critical for project leaders to identify the core partners who are needed both to launch the work and to sustain it over the long term. Although some of the MSP projects involved partnerships that were formed during the proposal development process, the case MSPs were each able to build on existing institutional partnerships, capitalizing on long-standing relationships among important players in these institutions. These prior connections enabled project leaders to draw on their knowledge of individuals and organizations that already had shared goals around strengthening teachers' content knowledge and pedagogical skills and were interested in collaborating.

The CAMS MSP, for example, extended partnerships established by MISE over a 10-year period preceding the MSP program. From 1993 to 2003, MISE had worked with school districts near Merck facilities in New Jersey and Pennsylvania, helping the districts move science education toward a more inquiry-based approach. Over time, MISE's work had become increasingly focused on deepening teacher understanding of essential science concepts and how to teach them effectively. When the MSP opportunity presented itself, MISE identified as partners two school districts (Linden and Rahway) with whom the organization had partnered since 1993. Kean University was identified as a higher education partner because of its proximity to partner school districts, and the fact that the university was responsible for preparing many of the teachers who would teach in the partner school districts. The Hillside school district was brought into the MSP partnership, in part, because it had been working with Kean to implement inquiry-based science instruction. The four school districts that ended up as partners were all in the process of improving science instruction when the MSP began. Their geographic proximity facilitated the sharing of resources within the project. Involving Kean University increased alignment between teacher preparation in mathematics and science and the vision of high quality science teaching underlying the MSP, with the expectation that future science teachers would be better prepared for work in the partner districts.

Like CAMS, PR–MSP built on partnerships that had been developed through prior NSF mathematics and science education grants. Notably, the Puerto Rico Department of Education was identified as a core partner for the MSP project, with the expectation that more integral involvement than in previous initiatives would facilitate the alignment of K–12 policy with the PR–MSP vision both during and after the MSP funding period. As a result of these efforts to nurture the partnership, PRDE developed plans to continue some of the work that the PR–MSP had begun; and external funding was sought to maintain the PR–MSP center at the Principal Investigator's campus to oversee on-going efforts at mathematics and science education improvement at both the K–12 and university level.

TxMSMP capitalized on prior relationships between the Department of Mathematics and Statistics at Stephen F. Austin State University and districts in the region in creating the partnership. Project leaders recognized that involvement of the Department of Secondary Education and Educational Leadership would also be essential for the program's success and included faculty from that department in the planning of the initiative.

SCALE 's attempts to develop and nurture a productive partnership that would be sustained over time confronted challenges unique to the project and to the setting in which it was implemented. This national-level project built on existing relationships between the Institute for Learning at the University of Pittsburgh and the Los Angeles Unified School District (LAUSD). Local universities were identified to partner with LAUSD, including two universities with a history of providing professional development in mathematics and science to LAUSD teachers (California State University, Dominguez Hills and California State University, Northridge). Although the University of Pittsburgh dropped out of the project early on, the University of Wisconsin continued to manage the work. While a productive partnership was maintained between the University of Wisconsin, local universities, and LAUSD throughout the MSP-funded period, developing and implementing the various interventions consumed so much time and resources that the local university/K–12 partnership was not developed sufficiently to maintain momentum when the MSP grant ended, especially in the face of a great deal of administrator turnover in the school district.

The examples above highlight the importance of building on existing partnerships, and of meeting the needs of the district partners, in order for the partnership to be valued and the work to be sustained beyond the funding period. At the same time, partnerships have to begin somewhere and at some point in time. In settings where partnerships must be launched from the ground up, a sensible approach would be to start small, perhaps working with a subset of the targeted teachers, making sure that the interventions that are implemented meet the needs as perceived by the core partners, and attending to nurturing partnerships even if it means slower progress in scaling up activities.

Key idea: Involve leaders from the core partners in the work in order to nurture the partnership.

Once core partners are identified, it is crucial to involve them in the work in order to nurture the partnership and develop an "institutional memory" as a partnership—thus making the partnership an entity in its own right that could potentially sustain the reform once the funding period ends. In Puerto Rico, for example, MSP leaders from the university had learned through prior projects that engaging the Puerto Rico Department of Education more integrally during the grant period would be critical to sustaining the work when MSP funding ended. Consequently, PRDE staff were invited to all planning meetings and kept fully informed of project activities.

The CAMS partnership was developed and nurtured through the creation of the Consortium Management and Oversight Committee (C-MOC), which included MISE staff, superintendents or their designees from each of the four districts, and Kean University deans and STEM department chairs. It was hoped that the inclusion of major decision-makers from each organization in regular meetings of the C-MOC would help engage all partners, develop a shared vision, and ensure that the needs of each partner were met. The strategy was quite successful for the district partners, which developed a sense of cooperation and shared resources and responsibilities. In contrast, the partnership with Kean University did not fully develop as planned; there were several different representatives from Kean over the life of the project, and they typically did not have the ability to make decisions for the multiple departments involved in CAMS.

Key idea: Attend to the needs of K–12 mathematics/science education as perceived by core partners.

Strategic coalitions consider the needs of each partner and seek ways to address their priorities. In this way, shared goals and values can be established, and activities can be planned to meet the needs of each partner. Being responsive to partner needs was vital to nurturing on-going support in the case MSPs. For example, TxMSMP addressed the needs of the K–12 education system on several levels. Many school districts in the region faced a shortage of qualified middle and secondary grades mathematics teachers, and student performance on state-mandated mathematics exams was low. At the state level, there were changes in accountability policies for teachers and students, including new teacher certification standards and exams and state-mandated curriculum standards and assessment instruments for students. The fact that the MSP targeted needs at both the state and local school district levels encouraged participation in the project, and provided a rationale for continuing the coursework for teachers beyond the MSP period.

Similarly, the PR–MSP addressed the needs of the Puerto Rico Department of Education to provide professional development opportunities for teachers. At the time the MSP grant was awarded, PRDE had no science supervisors and provided few science professional development opportunities for teachers. The MSP filled a void by offering a service that PRDE was not able to provide at that time. In addition, MSP leaders selected topics for professional development that were aligned with PRDE science standards, and that were identified as areas of high need by teachers. This alignment helped secure commitment from PRDE and the schools themselves to the on-going MSP work.

As the SCALE MSP was beginning, a new science director was appointed in LAUSD. He and others in the district recognized that many of the district's middle school teachers had only general education certification and needed a strong grounding in content and inquiry-based teaching. The district was looking for an affordable way to support teachers in increasing their content knowledge and inquiry-based teaching skills, and viewed the immersion unit approach as more affordable than purchasing commercially-available science modules. Hence, the SCALE vision for science education, coupled with the experience of university partners in developing inquiry-based immersion units, aligned quite well with the direction in which the district hoped to move. This alignment enabled the development and implementation work to proceed with full district cooperation.

Lesson 2: Consider how to engage a range of important stakeholders whose support is important for efforts to deepen teacher content knowledge.

The previous section discussed the importance of involving institutional leaders in developing productive partnerships; support from stakeholders at the highest level of organizations, e.g., commissioners of education, university presidents, and district superintendents, is important for getting institutional commitment. There is another "layer" of stakeholders who are also not likely to be involved in day to day details, but whose support—or opposition—can make or break the initiative. For example, although school administrators may not be asked to sign letters of support for a proposed project, teachers are more likely to participate in content-focused professional development, and to apply what they are learning to their instruction, if they believe that their principals think that work is important. Similarly, university faculty members are more

likely to commit their time and energy to launching and sustaining an initiative if they believe that their department chairs and colleagues value these efforts.

Three key strategic ideas characterized the work of the case MSPs in developing support among influential stakeholders within the partner organizations as the projects unfolded.

> ***Key ideas for working with a range of important stakeholders within partner organizations***
>
> *Identify the stakeholders whose understanding and support will be crucial for the work to be sustained.*
>
> *Involve stakeholders in activities that help develop a shared vision around deepening teacher content knowledge.*
>
> *Anticipate that changes in stakeholders may create new opportunities and/or barriers to sustainability.*

Key idea: Identify the stakeholders whose understanding and support will be crucial for the work to be sustained.

The people who are instrumental to launching an initiative should anticipate that others may not be as enthusiastic and invested in this work as they are. Project staff in each of the case MSPs came to realize, if they had not initially, that it was important to identify the key stakeholders within the partner institutions whose support "mattered" if the work was to be continued beyond the funded period. They developed mechanisms to ensure that these key stakeholders would recognize the importance of deepening teacher content knowledge and the value of the MSP strategies for doing so.

TxMSMP's establishment in the Department of Mathematics and Statistics at Stephen F. Austin State University helped to create strong support among a broad range of faculty members for the work of deepening teachers' content knowledge. The university had been founded with a primary mission of preparing K–12 teachers. The long history of the university's involvement in providing teacher training, curriculum development, and outreach to teachers in nearby districts meant that there was support among faculty within the Department of Mathematics and Statistics from the beginning. The fact that the PI was also chair and a highly respected member of the department positioned the MSP's work with teachers as a priority.

SCALE project leaders sought to develop support within the Los Angeles school district by adopting a "middle-out" approach in which they worked through science supervisors and specialists. The rationale was that, given frequent changes in superintendents, it would take these middle-level staff to maintain a focus and priority on the work at various levels within the system, both during the funded period and beyond.

In the PR–MSP, project leaders initially focused on developing support at the upper levels of the Puerto Rico Department of Education. As the project progressed, they gave increasing attention to developing support among regional superintendents, as they oversaw teacher participation in the MSP professional development. To cultivate long-lasting working relationships among

institutions, project teams that had been created to support the professional development efforts were expanded over time to include more members from schools, the Department of Education, and universities.

CAMS developed a tiered organizational structure not only to do the work of the project but also to keep various stakeholders informed as the work progressed. Representatives from partnership-wide management and implementation committees served as liaisons to their respective organizations, working with an Internal Planning and Implementation Team (I-PIT) of principals, teachers, and, in some cases, parents, representatives of teacher unions, and students. The liaisons from the partnership-level planning team kept I-PIT members informed about the work and involved them in local level decisions. This organizational structure constituted a vertical pathway of communication, and helped educate key stakeholders about, and engage them in the work of, deepening teacher content knowledge.

Key idea: Involve key stakeholders in activities that help develop a shared vision around deepening teacher content knowledge.

Once the key stakeholders are identified, and communication mechanisms established, project leaders need to figure out what to communicate, and how, so that these stakeholders not only understand the importance of deepening teacher content knowledge but also are prepared to support teachers in putting new knowledge and skills into practice.

SCALE worked to secure stakeholder support both within the local university system and among district science staff and teacher leaders by involving them in the development of immersion units and the professional development that would support those units. Project leaders also worked closely with district-level science supervisors, specialists, and advisors. These efforts helped develop support within the district for the immersion unit approach, resulting in LAUSD developing a less-comprehensive version of the units (known as "model lessons") as MSP funding ended.

Within CAMS, not only were district and school staff involved through planning and implementation committees, but professional development was offered to district and school administrators on the same science concepts, materials, and resources that teachers were learning about in their professional development. This coherence across activities helped develop and sustain a common language and vision about how deepening teacher content knowledge would strengthen mathematics and science education within and across partner school districts.

PR–MSP developed support among principals by forming school-level "base teams" of principals and selected teachers at each school. These teams were responsible for supporting mathematics and science education reform in their schools through professional learning communities. To prepare them for their roles, base teams participated in annual residential retreats that covered topics important to supporting MSP implementation, such as learning communities, conflict resolution, and team building. Regional superintendents were encouraged to participate in these activities as well. Engaging key stakeholders in this manner resulted in some regional superintendents and principals pledging to develop or maintain professional learning communities beyond the MSP period.

Key idea: Anticipate that changes in key stakeholders may create new opportunities and/or barriers to sustainability.

While leaders in the case MSPs were often strategic in engaging key individuals initially, changes in leadership at the K–12 level created challenges in terms of stakeholder support, as the SCALE MSP in Los Angeles illustrates particularly well. LAUSD experiences a great deal of turnover at all levels of the system, making it difficult to sustain a common vision for mathematics/science education. For example, only one leader in the LAUSD central office when the MSP began was still in place at the end of the MSP funding period. Also, a new superintendent had begun implementing a cross-disciplinary learning team approach that was pulling science teachers out of department meetings, potentially undermining the development of professional learning teams that the MSP had promoted.

On occasion, changes in key stakeholders provide unforeseen opportunities as well. For example, midway in the TxMSMP project, a new Provost and a new Dean of the College of Science and Mathematics were appointed at Stephen F. Austin State University. Both had prior connections with the university, knew the TxMSMP PI, and were familiar with the project goals. As a means to "research, develop, implement and disseminate best practices in STEM education," the administration and project PIs proposed a STEM Research and Learning Center for the SFASU campus, thus increasing the likelihood that the TxMSMP work would be sustained.

Lesson 3: Help ensure that key policies in the system are aligned with the vision underlying the reform efforts.

In developing plans to improve teacher content knowledge in mathematics and science, MSPs had to ensure that their planned interventions were, if not fully aligned with state and district policies, sufficiently well-aligned to permit implementation. For example, if a district had a strict policy on number of hours that teachers could be out of the classroom, then the professional development could not exceed that number or teachers would not be able to participate. This sort of alignment was essential to obtaining stakeholder support initially—and to ensuring buy-in for implementation. In the case MSPs, there were also examples where the influence was in the other direction, with efforts to align district and university policies to the project vision aimed at increasing the likelihood of on-going improvement after the funded period. The cross-case analysis suggested two key ideas related to policy alignment.

Key Ideas for aligning policy

Identify the most pertinent and influential policies and align interventions with those policies.

Work to align institutional policies with the project vision.

Key idea: Identify the most pertinent and influential policies and align interventions with those policies.

In order to ensure the participation and support of partner institutions, project leaders had to first identify the most influential policies and ensure that the interventions were well-aligned with those policies. For example, SCALE aligned the immersion units and corresponding professional development with district standards and expectations, allowing LAUSD leaders to

select the topics for which immersion units were developed, with guidance from the project that the topics should focus on areas in which district students performed poorly on the state test and/or that teachers had difficulty teaching. SCALE also worked to align the project vision of improving teachers' content knowledge, including pedagogical skills, with the district's vision by linking the MSP work with the district's new science education plan.

The PR–MSP initially selected topics for professional development through a needs assessment administered to teachers; project leaders narrowed the list of possible topics by selecting those that were most closely aligned with Puerto Rico's science standards. The workshops were aligned with PRDE's continuing education policies for teachers in that teachers received credit for professional development activities, which could be applied toward moving up the career ladder and subsequent salary increases.

Key idea: Work to align institutional policies with the project vision.
With planned interventions that were aligned with state and district standards and policies, leaders in the case MSPs worked to ensure that other policies and practices within the partner institutions became more aligned with the MSP vision of improved teacher content knowledge and pedagogical skills. For example, as a result of efforts to develop a common vision among district leaders, administrators in CAMS districts and schools sought to hire teachers whose vision of instruction was consistent with the project vision.

TxMSMP provides a striking example of policy and structural alignment within the university, which facilitated the creation of two graduate degree programs for teachers that could win approval and be sustained over time. After encountering resistance from mathematics faculty to using a mathematics prefix for courses that did not target the advanced level of disciplinary content typical of graduate mathematics courses, MSP leaders offered the courses with a graduate-level mathematics education prefix. Also, rather than go through the extensive approval process required to create a new degree program, MSP leaders resurrected an existing, inactive degree program. The result of these efforts to align MSP and university policies was that the new degree program was approved by the Texas Higher Education Coordinating Board, enabling teachers participating in the MSP to pursue Master's degrees in School Mathematics Teaching at the Middle or Secondary Level. Those courses are still in place—and the university has been able to leverage additional funding from the Coordinating Board to provide a track for teachers who not only seek to become Master Mathematics Teachers, but also want to transition to an M. S. in Natural Sciences.

Lesson 4: Design and implement professional development that is both feasible and likely to be effective with the teachers in the particular context.
To effect lasting change in mathematics and science education, MSPs had to be strategic in designing interventions that would deepen teachers' understanding of important concepts and how to teach them. Cross-case analysis identified several key ideas about how decisions made about interventions increased the likelihood that the interventions would be effective and that there would be a sustained impact over time.

Key ideas about designing teacher interventions strategically

Choose interventions that both address perceived needs explicitly and are likely to contribute to long-term improvements by focusing on more entrenched issues.

Recognize the pros and cons when considering incentives for teacher participation in professional development.

Have a plan for addressing varying levels of teacher knowledge and skills.

Provide support for application of enhanced teacher content knowledge to the classroom.

Key idea: Choose interventions that both address perceived needs explicitly and are likely contribute to long-term improvements by focusing on more entrenched issues.

There were a number of considerations for MSP project leaders in designing interventions that would enhance teacher content knowledge. First and foremost, the intervention had to address the needs of partner districts as teachers and other stakeholders perceived them—which typically meant the professional development had to be seen as directly relevant to teachers' classroom practice—or districts would be unlikely to participate.

SCALE addressed its goal of developing teacher content knowledge and pedagogical skills through immersion units that were aligned with district standards and expectations. Immersion units were appealing to LAUSD science leaders because they provided instructional materials that were less expensive than "off the shelf" science modules, both in initial cost and as they required refurbishing, and were more tailored to the district's needs. At the same time, the immersion unit approach was selected because the leading project partners at the University of Wisconsin and the University of Pittsburgh had success developing and implementing such units in prior work. By focusing its work with teachers on these units, SCALE deliberately made available carefully-developed instructional materials that could not only be used by participating teachers beyond the funded period of the MSP, but also be shared with new teachers in the schools where a high rate of teacher turnover is a fact of life.

Similarly, CAMS offered professional development for middle grades science teachers focused on instructional materials. Since adopting instructional materials for classroom use is something school districts must do, CAMS offered a combination of supporting districts in their selection of commercially-available science modules to anchor the curriculum, then providing professional development to teachers to help them implement the modules. This strategy had been effective in a previous project involving many of these same partners, in that case focused on elementary science, so CAMS had confidence in the approach.

As another example, professional development topics addressed in the PR–MSP were selected to align with the Commonwealth's science standards as well as teachers' perceptions of their needs. At the same time, project leaders knew from prior work focused on supporting implementation of science instructional materials that teachers needed a solid grounding in content knowledge to

use their materials well, so the professional development was focused on deepening teachers' knowledge of the concepts underlying the science standards teachers are expected to address.

Finally, TxMSMP project leaders crafted their degree programs to specifically target under-prepared middle and secondary mathematics teachers. The many rural districts that were partners in the MSP were well aware that a significant number of their mathematics teachers had minimal content preparation and could benefit from the degree programs. For their part, the university faculty took the opportunity the MSP funding offered not just to shore up content deficiencies or address state requirements, but to create a program that embodied what they believed, and state and national recommendations suggested, was truly necessary as a solid foundation for mathematics teachers.

Key idea: Recognize the pros and cons when considering incentives for teacher participation in professional development.

To engage teachers in work to strengthen their content knowledge and pedagogical skills, MSPs offered incentives for their participation in MSP courses and workshops. These incentives ensured teacher participation at least initially, until evidence could be provided that the professional development was worthwhile. The case MSPs offered a variety of incentives, including stipends for participation, credit toward advanced certification or salary increases, and instructional materials for classroom use.

In PR–MSP, the professional development itself was offered through regional resource centers in order to make it accessible to teachers across the island. Teachers also received stipends for participation in the workshops. SCALE provided two types of incentives for participating teachers: stipends and substitute teachers.

In TxMSMP, teacher participation in the degree programs was encouraged through project payment of tuition, travel expenses, and a summer stipend. This level of incentive was appealing to both participating teachers and the partner districts. However, when the funding period ended, districts were not able to support costs to have additional teachers complete the full degree programs, so alternative ways of engaging additional teachers that would be less costly were being explored.

CAMS chose not to provide stipends to teachers for participation in professional development in large part because doing so was considered unsustainable. Rather, participating districts could provide incentives to teachers at their discretion, which would have to come from other funds that were considered more likely to be available in the long term.

Key idea: Have a plan for addressing varying levels of teacher knowledge and skills.

MSP leaders were sometimes surprised at the wide range in content knowledge among participating teachers, and over time learned how to plan to accommodate the differences. In addition, some districts had high rates of teacher turnover, so projects had to plan professional development for both new and veteran teachers. Other projects found that many teachers needed more background knowledge than they had anticipated, and consequently had to adjust the program selection criteria and/or the coursework.

For example, TxMSMP found that many of the teachers initially accepted into the program were not sufficiently prepared to successfully complete the program; in fact, fewer than half of the first cohort passed the Texas Master Mathematics Teacher Certification exam. Rather than "watering down" the graduate programs, project leaders tightened the selection criteria, modified plans of study to include more intensive preparatory work at the front end to shore up fundamental knowledge, and provided remediation opportunities prior to the state exam. Similarly in CAMS, when professional development providers reported different needs of teachers due to teacher turnover, introductory workshops were offered to teachers new to the instructional materials, while more in-depth, content-focused curriculum workshops were offered to teachers who had taught the modules previously.

Key idea: Provide support for application of enhanced teacher content knowledge to the classroom.

To ensure that the content knowledge and pedagogical skills teachers acquired during professional development would be applied effectively in their work with students, the case MSPs offered classroom support such as coaching or mentoring; they also timed school-year sessions to coincide with teaching the content covered in the professional development.

CAMS worked to facilitate the application of teacher knowledge and skills to the classroom by focusing their professional development and support strategies on the school curriculum. As the project evolved, the timing of the academic-year professional development sessions was adjusted to coincide with implementation of the units in order to help teachers transfer what they had learned during summer curriculum workshops to classroom practice.

Application of knowledge was also built into the TxMSMP design in several ways. First, the mathematics content courses in the degree programs were designed specifically for middle and secondary teachers, so content and pedagogy were integrated in all courses. Second, as a major cumulative assignment in their degree programs, participants completed a teaching portfolio that emphasized the connections between mathematics content that teachers were learning and their application in classroom teaching practice. Finally, through the opportunity for TxMSMP teacher participants to lead summer enrichment math camps for students, teachers had a chance, outside of the typical pressures and routines of their classrooms, to practice teaching content they had addressed in their coursework using new pedagogies.

In contrast, both the Puerto Rico and SCALE MSPs intended to provide more support for classroom implementation than actually occurred, primarily because the projects' attention, energy, and resources were directed at designing professional development and/or instructional materials. In PR–MSP, plans for classroom visits by project leaders did not occur until near the end of the project, and while there was evidence that the project was beginning to implement coaching by lead teachers, the strategy faced considerable challenges. Daily class schedules did not allow much time for the lead teachers and classroom teachers to meet, and teachers were unused to discussing their practice with other teachers. Similarly, in SCALE, plans for content-focused teacher study groups and cross-visitations of classrooms by teachers did not materialize as intended—although study groups did develop in some schools at the initiative of principals and teachers. A plan to offer school-year sessions that would coincide with teaching of the immersion units proved to be nearly impossible to coordinate due to different school schedules

across the district. In retrospect, a project leader noted that it might have been better to reduce the level of effort spent in developing and providing initial professional development and devote more resources to helping teachers apply what they were learning to their instruction.

Lesson 5: Use data to inform decisions, improve the quality of the interventions, and provide evidence to encourage support for system change.

As noted in the *Handbook* on strategic leadership, the MSP program builds the use of data and evidence into project design and reporting. Projects are expected to implement approaches that have evidence of effectiveness in similar situations, and to provide evidence that their projects in fact produce the desired results in their particular contexts. The case MSPs used data to inform and support their work before the project began, during implementation, and near the end of the funding period. Two key ideas emerged about the strategic use of data to support interventions to strengthen teacher content knowledge.

Key ideas for the strategic use of data to inform, support, and sustain reform

Use data to inform decisions about selecting, implementing, and adapting interventions.

Use data to ensure an acceptable level of quality during implementation and scale-up, and to encourage support for system change.

Key idea: Use data to inform decisions about selecting, implementing, and adapting interventions.

As part of their proposals for funding, MSPs needed to make the case that the interventions they proposed were likely to be effective, based on evidence of their previous effectiveness in similar settings. Accordingly, the case MSPs selected or adapted interventions based on evidence from prior projects that the interventions were effective in improving teacher content knowledge in ways that influenced teacher practice.

SCALE selected the immersion unit approach because leading project partners at the University of Wisconsin and the University of Pittsburgh had experience developing investigation-based projects, which had been implemented on a pilot basis. Preliminary results suggested that these sorts of projects were engaging and interesting to students. SCALE leaders hoped that by using immersion units as a focus of their work, quality science instruction would become available to all students.

Project leaders of TxMSMP based much of their course design on one of the co-PI's prior work with middle grades teachers. Results from these experiences suggested the need for an on-going program of study to address mathematics content in-depth, and with connections across mathematics topics, as well as to the work of teaching mathematics.

CAMS coaches employed by the districts received extensive training so they would be able to support classroom change, not only during the MSP, but also when project funding ended. Although coaches were initially intended to provide support to a large number of teachers, including those new to teaching science, it became clear as the project progressed that teachers

often needed more help from the coaches than the project leaders had anticipated. To enable the coaches to provide the depth of support needed to make a difference, CAMS decided to reduce the number of teachers assigned to each coach and to focus their efforts on working with teachers who had attended CAMS professional development.

Key idea: Use data to ensure an acceptable level of quality during implementation and scale-up, and to encourage support for system change.

MSPs were required to include evaluations both to provide feedback on the quality of implementation and to assess impact. The case MSPs illustrate how data collected during the early stages of an initiative can be used to improve the interventions. For example, the CAMS evaluation included classroom observations, which pointed to a need to strengthen teacher understanding of fundamental science concepts, as well as pedagogical practices to support inquiry-based instruction. In response, CAMS leaders revised the curriculum workshops and in-class coaching to try to deepen teachers' understanding of the concepts and how to teach them, moving teachers away from a focus on the logistics of implementing the modules in their classrooms. For example, conceptual flow diagrams were presented to teachers during curriculum workshops to help them understand the content "story line" of the instructional materials.

PR-MSP leaders acted on data, gathered from facilitators and participants, that indicated the initial professional development was not meeting the needs of K-3 teachers. To help ensure that PR-MSP met the needs of teachers at all levels, science liaisons were assigned to specific grade ranges. Throughout the project, facilitators adapted the pacing and, to some extent, the content of professional development to address teachers' needs. In addition, a new strategy, communities of practice, was developed to provide professional development for small groups of teachers around common interests they wanted to pursue.

In addition to helping make mid-course corrections, projects can use evidence to help garner the support of important decision-makers and stakeholders for continued implementation of the interventions. TxMSMP project leaders, for instance, were able to point to evidence that the TxMSMP had a positive impact on participating teachers' mathematics content knowledge and instructional practices to help ensure that districts in the region would continue to see the value of partnering with the university.

Lesson 6: Work to develop capacity and infrastructure to strengthen teachers' content knowledge and pedagogical skills, both during the funded period and beyond.

MSPs had to plan from the beginning for how they would develop the capacity and infrastructure of local school districts and higher education institutions to do the work in both the short and long term. Strategic MSPs kept the goal of capacity-building at the forefront throughout the project, with the partners working together to develop a plan for helping to ensure sustainability of their efforts. Maintaining a focus on capacity-building was challenging because of the enormous energy and attention required to develop and implement the interventions, and some projects were more successful than others in this regard. Four key ideas emerged about developing capacity and infrastructure in ways that would contribute to sustainability.

Key ideas about developing capacity and infrastructure to sustain the improvement process

Consider from the get-go how to develop capacity for long-term sustainability.

Plan for broader scale implementation as you develop the initial program plan.

Plan for succession of project leaders.

Identify and develop the infrastructure needed for the work to be sustained.

Key idea: Consider from the get-go how to develop capacity for long-term sustainability. Including educators from partner districts in selecting, developing, and implementing interventions helped garner district support in the case MSPs. Equally important, the inclusion of teacher leaders and other district personnel in project activities helped develop the local capacity and will to carry on the professional development and related interventions after MSP funding ended.

In SCALE, university project leaders used an apprenticeship model to build a shared vision and develop the capacity of educators in LAUSD and at the partner California universities to engage in similar work beyond the funding period. For instance, K–12 Science Leadership Institutes were held to support district leaders in understanding and applying research on systemic science education reform, and to develop their capacity to employ a coherent approach to teacher professional development. Through the Professional Development Study Group, University of Wisconsin Faculty worked intensively with about 60 teachers, science supervisors, university STEM faculty, and science education faculty to help them develop and deliver professional development to teachers around the immersion units. As project funding ended, LAUSD was developing a professional development structure similar to the Study Group approach. In addition, participation by district science staff, lead teachers, and California State University STEM faculty in the Study Group meant that SCALE left behind a large cadre of university and LAUSD staff with the knowledge and skills to design and facilitate professional development focused on developing teachers' content knowledge and pedagogical skills.

In TxMSMP, project leaders used a team teaching approach to expand the number of university mathematics faculty with experience in course development and facilitation for the teacher degree programs. The team-teaching model helped develop sufficient capacity that individual faculty members would be able to continue to teach the courses effectively later on. Project leaders also hoped to develop capacity by enlisting mathematics graduate students to take over (from mathematics faculty) the responsibility for mentoring participating teachers. By involving graduate students in the MSP, project leaders hoped to extend the project's impact on mathematics teaching and learning at the post-secondary level, potentially helping to prepare the next generation of college and university mathematics faculty for work with mathematics teachers.

In CAMS, instructional teams were created to develop and deliver professional development to teachers. Each team included two teachers and a science content expert that might come from MISE or Kean University. Veteran teachers were paired with teachers new to the instructional teams in order to increase capacity, and to groom new leaders within each district.

In PR–MSP, university faculty and exemplary teachers from across the Commonwealth were involved in the design and delivery of professional development, using a train-the-trainers model. Resource teachers who staffed the regional centers participated in multiple workshops to prepare them for their roles, and they were also invited to participate in teacher professional development. The result was that the MSP expanded the cadre of university faculty and teacher leaders with the knowledge and skills to offer teacher professional development focused on fundamental science concepts. However, despite progress of these efforts, the MSP was unable to develop sufficient capacity to reach all schools as originally planned.

Key idea: Plan for broader scale implementation as you develop the initial program plan.
One of the challenges associated with having external funding is to resist the urge to develop interventions that are too expensive to be implemented at scale once the grant has ended. The case MSPs provide examples of planning for how the interventions would be implemented on a broader scale over time, e.g., codifying tools that local implementers could use to continue the work after the funding period. For example, student assessments were used in CAMS to support teachers' examination of student understanding. The assessment and data gathering activities were initially the responsibility of the Educational Testing Service—a project partner. During the MSP period, ETS scaffolded the transfer of these responsibilities to the partner school districts so that, by the end of the MSP period, districts had assumed responsibility for collecting, analyzing, and reporting CAMS assessment data.

The course materials created by TxMSMP were packaged and made accessible to faculty at other institutions. These materials were reportedly being used at numerous universities and regional service centers. Similarly, the PR–MSP project leaders posted materials developed during the MSP period on the project's website so that they could be available across the island. SCALE-developed immersion units were intended to be used beyond the funding period. And, in fact, the units continued to be requested by teachers in the years after SCALE funding ended. The district also developed its own, less comprehensive version of the immersion units known as "model lessons," which were short units focused on topics contained in district assessments.

Key idea: Plan for succession of project-level leaders.
Over time, project leaders will move on to other pursuits, including retirement. To help ensure that the improvement efforts will be sustained, it is important to identify the next generation of leaders and involve them in the work.

The PR–MSP Principal Investigator had been identified by the head of a previous science education initiative in the commonwealth as a potential future leader, and her involvement in the earlier work helped prepare her for a leadership role in planning and implementing the MSP. Similarly, the TxMSMP illustrates how involving potential leaders can help ensure leadership succession. The project's original Principal Investigator had long been a leader in mathematics teacher preparation across the state, and had secured many prior grants to support mathematics

education reform. When he passed away midway through the project, other co-PIs at the university were poised to assume leadership by virtue of their prior involvement with the MSP and similar work. One co-PI became the new PI of the MSP; another co-PI became the mathematics department chair.

SCALE had a plan for leadership succession from the beginning—although the plan did not succeed as well as project leaders had hoped. While the project itself was led from a distance—first by the Institute for Learning at the University of Pittsburgh and then by the University of Wisconsin—project leaders identified and engaged California State universities as partners in the project because those universities sent a majority of the teachers they prepared into LAUSD. University of Wisconsin leaders of the MSP hoped to facilitate the creation of a K–12/higher education partnership and infrastructure in the Los Angeles area that would continue implementing MSP-like opportunities after the grant period. However, this infrastructure did not become fully established, partly because project leaders ran out of time to complete the process when other activities consumed so much time and energy. The lesson here may be that plans for succession should be considered as integral as the actual intervention work to bolster the chances for sustainability after grant funding ends. At the same time, the high turnover rates in leadership at all levels in large districts such as LAUSD make it difficult to plan effectively for succession.

Key idea: Identify and develop the infrastructure needed for the work to be sustained.
As part of their work, the MSPs created new positions, negotiated for office and meeting space, arranged for release time for staff members, and appointed committees to oversee and manage implementation during the grant period. Some of the case MSPs also worked to develop structures that could be maintained after the funding period.

For example, the PR–MSP developed a regional service center structure through which to offer professional development and resources. This structure was effective enough that PRDE hoped to support regional service centers through federal funding when the MSP grant ended.

In TxMSMP at the university site, on-going collaborative project meetings were held between the mathematics and secondary education departments to share expertise and ideas about program revisions. Mathematics and education faculty were enlisted to co-plan and co-construct the graduate coursework, with the intent that, once established, these collaborative modes of working would continue in future efforts to improve K–12 mathematics teaching and learning. The likelihood of such on-going work was substantially enhanced when a new Dean of the College of Sciences and Mathematics was appointed at SFASU while the MSP was actively implementing its degree programs for mathematics teachers. The new Dean viewed TxMSMP's work as a prototype for the College's work in STEM education, which ultimately led to the creation of a STEM Research and Learning Center for the SFASU campus. The hope was that this center would house the continuation of TxMSMP's work as well as other mathematics and science education reform efforts in the future. Not coincidentally, the PI of TxMSMP was later appointed director of the STEM Research and Learning Center as well as Associate Dean of the College of Sciences and Mathematics.

In CAMS, considerable attention was given to developing a partnership infrastructure among school districts that would endure beyond the funding period. The tiered committee structure developed within CAMS involved educators from all four districts in a collaborative effort to oversee, manage, and implement the work. The project management committee (the C-MOC) was intentional in allowing the planning and implementation committee (C-PIT) to make implementation decisions in order to develop capacity at those levels. The idea was to develop a sense of community among the partner districts that would enable them to share resources and expertise outside of supports provided by external partners such as MISE. And there were signs that this strategy was paying off, as the partner districts began to open their professional development offerings to participants from other districts. For example, a partner district that had sent some principals to the *Lenses on Learning* (Grant, Davidson, Weinber, Nelson, Sassi, & Bleiman, 2003) training program offered through CAMS subsequently began providing the training for principals throughout the district, and offered the opportunity to the other CAMS districts to send principals as well. As CAMS funding ended, collaboration between MISE and the districts continued, although partnership-wide meetings occurred less frequently.

Conclusion

This report began by suggesting several components of reform that are important in creating coherence and alignment around policies and practices for improving teachers' mathematics and science content knowledge in ways that contribute to sustained improvement, based on the experience of earlier large scale reform efforts (Weiss et al, 2004). Data from four projects implemented in the period from 2002 to 2010 were used to see how those ideas played out in the context of the NSF-supported MSP program. Key ideas about how project leaders can help ensure that their efforts to deepen teacher content knowledge will be sustained have been provided throughout this report. These key ideas have been illustrated with examples from the case MSPs to show what these ideas looked like in practice, and the challenges associated with addressing them.

Ideally, project leaders will consider all of the highlighted ideas in designing and implementing improvement plans, but the reality is that local policies and structures—as well as the ambitious goals established by project leaders—may make it difficult to address all components simultaneously and with equal effectiveness. The MSP case examples illustrate the trade-offs project leaders had to negotiate as they developed and carried out their plans. For example, leaders of the SCALE MSP had a plan to ensure succession of leadership, but the intense work in developing and implementing the interventions with teachers left little time and energy to devote to that area. And while the Puerto Rico MSP had intended to greatly expand the number of schools served by the end of the MSP period, the initiative was not able to develop sufficient capacity for that rate of scale up. CAMS leaders planned for coaches to provide site-based support to a substantial number of middle school teachers in partner districts, but adjusted this expectation as it became clear that more in-depth support was needed to improve the quality of science instruction. TxMSMP intended to develop capacity at other universities to deliver mathematics coursework that would produce more qualified middle and high school teachers, but ultimately devoted more effort to institutionalizing the coursework at the lead MSP university.

Perhaps a guiding principle when project leaders must make trade-offs is to consider which components will contribute to improving teachers' content knowledge and pedagogical skills over the long term—well beyond any grant-funded period. Reform leaders cannot expect that the interventions they develop will remain fully intact once substantial funding from grants such as the MSP has ended. But they can work to leave partners with a *vision* of what mathematics and science instruction should look like, the *will* to continue pursuing that vision through whatever means are available, some *models* that may be used or adapted to enact the vision, and the *capacity* to implement these models.

CAMS benefited from the presence of MISE as an external partner providing on-going intellectual and financial resources for the partnership. At the same time, the attention that CAMS leaders gave to developing and institutionalizing the partnership contributed to the partner districts assuming some of the work on their own. Collaboration among the districts continued beyond the MSP, and a partnership of MISE and several districts is building on work supported by CAMS to effect further improvements in science education.

The other three case MSPs also created a vision for mathematics/science education reform that university and/or school district leaders have continued to pursue. The Puerto Rico Department of Education was working with the University of Puerto Rico to use federal funding to continue utilizing the regional service center structure and the cadre of professional development providers who were prepared during the MSP period. This continuation was possible because of the attention the PR–MSP gave to developing a productive partnership between the university system and PRDE, and developing the capacity and infrastructure to support a new vision for mathematics and science education.

As SCALE funding ended, the Los Angeles Unified School District was implementing model lessons that represented a reduced version of the immersion units developed through the MSP. Moreover, the continued use by the district of the Professional Development Study Group approach to design professional development provides an example of how the MSP developed capacity for the district to continue elements of science education reform on its own. In addition, science faculty who were involved in the Professional Development Study Group reported that their participation had made them see the need to use better pedagogy in their science courses, including inquiry-based activities, and there is some evidence of continued interest in K-12 education among participating STEM faculty.

In Texas, the graduate courses developed by TxMSMP continued to be offered, and university mathematics and education faculty were committed to working together to help improve in-service teachers' understanding and teaching of mathematics. The establishment of the STEM Research and Learning Center ensured the ongoing and future efforts would have an institutional home at Stephen F. Austin State University. These sustained features resulted from the MSP's attention to developing productive partnerships within the university, working to improve teacher content knowledge at a time when the state was in need of a larger number of qualified mathematics teachers, and leaving in place university leaders who understood and could support the work.

Deepening the mathematics/science content knowledge of large numbers of teachers in meaningful ways that will transfer to their classroom practice is challenging, requiring leaders to use available resources strategically. In all of the case MSPs, partner school districts started (or continued) on a trajectory to improve the content knowledge and pedagogical skills of mathematics/science teachers, although the process was often difficult. The lessons learned in the case MSPs have implications for the sustainability of efforts aimed at deepening teacher content knowledge, whether the initiatives receive external funding or are supported by the district's regular operating budget. It is important, the experiences of the case MSPs suggest, to develop partnerships to ensure appropriate expertise; to garner the support of influential stakeholders and work toward more aligned policy; to select interventions that show promise for the particular context, and refine them over time; and from the very beginning, work to develop the capacity and infrastructure needed to continue the process. Being strategic in designing, implementing, and sustaining effective efforts to deepen teacher content knowledge requires attending to these essential elements of the work, recognizing that there will be a myriad of trade-offs to consider and decisions to make as the process unfolds.

References

Banilower, E. R., Boyd, S. E., Pasley, J. D., & Weiss, I. R. (2006). *Lessons from a decade of mathematics and science reform: A capstone report for the local systemic change through teacher enhancement initiative.* Chapel Hill, NC: Horizon Research, Inc.

Desimone, L. M., Porter, A. C., Garet, M. S., Yoon, K. S., & Birman, B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. *Educational Evaluation and Policy Analysis, 24*(2), 81–112.

Fennema, E., Carpenter, T. P., Franke, M. L., Levi, L., Jacobs, V., & Empson, S. (1996). Learning to use children's thinking in mathematics instruction: A longitudinal study. *Journal for Research in Mathematics Education, 27*(4), 403–434.

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), 301–325.

Grant, M. G., Davidson, E., Weinber, A. S., Nelson, B. S., Sassi, A., & Bleiman, J. (Eds.). (2003). *Lenses on learning series.* Parsippany, NJ: Dale Seymour Publications.

Henze, I., van Driel, J. H., & Verloop, N. (2008). Development of experienced science teachers' pedagogical content knowledge of models of the solar system and the universe. *International Journal of Science Education, 30*(10), 1321–1342.

Hill, H. C., Blunk, M. L., Charalambous, C. Y., Lewis, J. M., Phelps, G. C., & Sleep, L. (2008). Mathematical knowledge for teaching and the mathematical quality of instruction: An exploratory study. *Cognition and Instruction, 26*(4), 430–511.

Ma, L. (1999). *Knowing and teaching elementary mathematics: Teachers' understanding of fundamental mathematics in China and the United States.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

National Science Foundation. (2003). *Math and science partnership program (MSP): Program solicitation (NSF 03-605)*. Washington, DC: Author.

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), 723–736.

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.

U.S. Congress. (2001). National mathematics and science partnerships act of 2002. Washington, DC: Author.

Weiss, I. R., Miller, B. A., Heck, D. J., & Cress, K. (2004). *Handbook for enhancing strategic leadership in the math and science partnerships*. Chapel Hill, NC: Horizon Research, Inc. http://www.horizon-research.com/reports/2004/mspta_handbook.pdf

Zucker, A. A., Shields, P. M., Adelman, N. E., Corcoran, T. B., & Goertz, M. E. (1998). *A report on the evaluation of the National Science Foundation's statewide systemic initiatives (SSI) Program*. Menlo Park, CA: SRI International.