Sustaining Improvement Efforts to Deepen Middle-Grades Teachers' Science Content Knowledge: The Case of the Consortium for Achievement in Mathematics and Science

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Joan D. Pasley
Patricia J. Kannapel

Horizon Research, Inc.

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MSP Knowledge Management and Dissemination
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Introduction

The National Science Foundation's Math and Science Partnerships (MSP) program, established in 2002, involves science, technology, engineering, and mathematics (STEM) disciplinary faculty and K–12 districts in partnerships to improve the quality of mathematics/science education in the participating districts 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 continue 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 each of a number of key areas, and situating those lessons in the broader education improvement knowledge base. Lessons learned about deepening teacher content knowledge have been a particular focus of the MSP KMD work for two reasons. First, the MSPs have devoted a great deal of effort to the professional development of teachers of mathematics and science. Second, professional development is the intervention of choice in many mathematics and science education reform efforts in the United States, with the expectation that enhancing teacher knowledge and skills will lead to improved teaching and learning. Lessons learned about designing and implementing professional development, especially programs that involve STEM faculty, 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[1]). That document suggests that strategic leadership in mathematics/science education improvement starts with understanding the system one is trying to improve. Strategic leaders then choose interventions that fit with the needs of that system, and are likely to be effective when implemented with the capacity that the partnership either already has or can develop. But capacity is not enough; at the same time, partnerships need to be sure that the system develops the will to improve, which involves getting key stakeholders on board, and ensuring that teachers get a consistent set of messages—from the partnership and from school/district curriculum, instruction, and assessment policies.

MSP KMD has conducted a series of case studies of MSP projects with the strategic leadership handbook in mind as a framework for understanding the partnerships between school districts and institutions of higher education. The goal was to describe how MSP partnerships were designed to foster sustained improvement in mathematics and science education, the nature of the challenges that these partnerships faced, and how those challenges were addressed, to help inform future efforts at system improvement.

This chapter is one of four case reports; it describes the Consortium for Achievement in Mathematics and Science MSP, a partnership between the Merck Institute for Science Education, Kean University, the Educational Testing Service (ETS), and the New Jersey public school districts of Elizabeth, Hillside, Linden, and Rahway. A cross-case analysis can be found here.

[1] 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.

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Vignette

A teacher circulates as students work, addressing questions that arise. At times she encourages students to revisit stations around the room to review the conductivity and magnetism of particular elements. After 15 minutes of group work, the teacher queries the class about patterns they have noticed in the properties of their elements. One group notes the difference in boiling point between elements that are solids and those that are gases in their natural states. Another group points out the luster of the elemental metals. The teacher then asks students to take out their periodic tables and locate the elements they have put in particular groups. Many students voice the observation that all gases are on one side while metals are on the other. The teacher concludes the discussion by telling students they will consider the connections between elements and melting points the next day.

During the past four years, this teacher has attended professional development as part of the CAMS MSP, learning to conduct inquiry-based science lessons where students make connections between the activities and the intended science content. As a result, she is able to help students understand that the periodic table is not an arbitrary arrangement, but rather reflects the properties of the various elements, which is an important foundation for future studies in chemistry.

The Consortium for Achievement in Mathematics and Science MSP

In 2003, the National Science Foundation (NSF) awarded a $7,025,426 grant to the Consortium for Achievement in Mathematics and Science (CAMS) through its Math and Science Partnership (MSP) program. CAMS was 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. For MISE and the Linden and Rahway districts, CAMS was the continuation of a history of collaboration that began in 1993, including a five-year Local Systemic Change grant from NSF that preceded the MSP. As in earlier work, MISE provided funding in addition to the NSF MSP grant.

CAMS focused on improving the knowledge and pedagogical skills of middle school mathematics and science teachers in four neighboring urban school districts—with the vision that all middle school students in those districts would understand and be able to apply key concepts in mathematics and science. The project goals would be accomplished through learner-centered, inquiry-based instruction. Teachers would be supported by a comprehensive professional development program, including Curriculum Workshops focused around specific instructional materials adopted by the school districts; and in-class support provided by mathematics and science coaches. CAMS included a teacher preparation component through Kean University's pre-service teacher education program, and the university conducted mathematics and science recruitment fairs in CAMS districts. This report focuses on the middle school science component of CAMS, first setting the context then describing the focus, goals, and plans for science education reform and how those plans played out over time. A summary of key factors in the implementation of the CAMS work on deepening teacher content knowledge and a discussion of the likelihood of lasting impacts conclude the case.

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The Context for Science Education Reform

The CAMS partners, with the exception of ETS, are located in Union County, New Jersey, which is about six miles southwest of Newark and within 20 miles of New York City. At the time the MSP proposal was submitted, Union County was home to about 525,000 residents in 21 towns and cities—the third most densely populated county in New Jersey. The partner school districts varied by size and previous attention to science education improvement; all served substantial numbers of minority and low-income students.

MSPs are intended to be partnerships between high-need school districts; the science, technology, engineering, and mathematics faculty in institutions of higher education; and, optionally, other partners such as state education agencies, public charter schools, businesses, and nonprofit or for-profit organizations concerned with mathematics and science education. The CAMS proposal was unique among MSPs in that the lead partner was a non-profit organization affiliated with a major corporation rather than a university. MISE was formed by Merck & Co., Inc. to improve science education in public school districts in New Jersey and Pennsylvania, where Merck has major facilities. MISE's efforts were built around a vision of learning in which inquiry is an integral and regular part of the learning experience of all students.

When MISE began its work in 1993, it partnered with five school districts including Linden and Rahway. Each of the school districts received support from MISE to develop a vision of inquiry-centered science instruction and craft a five-year strategic plan to realize that vision. The centerpiece of the work was selection of a set of commercially-available science modules that covered key state standards. These modules, such as those developed by the Full Option Science System, Science and Technology for Children, and Biology Sciences Curriculum Study, formed the core of the new science curriculum in the partner districts.

The MISE Partnership began its professional development work with teachers in 1994 with Leader Teacher Institutes that offered intensive professional development to selected teachers over a period of years to develop their knowledge and skills, and to prepare them to be science leaders in their schools and districts. Later, the Partnership obtained a five-year NSF Local Systemic Change (LSC) grant to provide professional development workshops on specific science modules to any K–8 teachers in the partner districts who wanted to attend. The focus of these workshops was on familiarizing teachers with the materials in the science modules. These workshops were the precursors to another level of workshops, developed during CAMS, for teachers who had used the materials for several years. Workshops at this level focused more strongly on the content undergirding the modules, as project leaders realized that teachers needed a firm understanding of science content in order to teach the modules effectively.

As the LSC funding period came to an end, MISE leaders saw the MSP as a vehicle for MISE to further its work to improve science education. The MSP program aims to increase the academic achievement of students in mathematics and science by enhancing the content knowledge and teaching skills of classroom teachers—the very areas on which MISE had focused over the years. Although MISE had previously focused on improving science education, CAMS included greater attention to mathematics in response to districts' perceived needs.

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CAMS focused on four districts situated near Merck's Rahway facility, including two of the LSC partner districts and two new districts, while MISE continued to support science education reform in the other LSC partner districts. One of the new districts, Hillside, had worked with Kean University on science instruction. In addition, one of the district leaders in the LSC project that preceded CAMS had, in the interim, become Hillside's superintendent. Kean 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. Involving Kean would increase the alignment between teacher preparation in science and mathematics and the vision of high-quality science teaching that underlies CAMS, so that future science teachers would be better prepared for work in the partner districts.

When the MSP began, Linden and Rahway school districts had already adopted science modules (through the earlier MISE partnership) to anchor the curriculum, and many teachers had received professional development on implementing these modules. Elizabeth and Hillside school districts were at earlier stages of adoption at the inception of the MSP. Just prior to submitting the MSP proposal, Elizabeth had identified inquiry-based science modules to replace traditional textbooks in grades K–8, with implementation to be phased in at different grade levels. Hillside had been working to implement inquiry-based science at the elementary level, and had begun the implementation of an inquiry-based science program at the middle school level just prior to the CAMS project. Although Elizabeth's and Hillside's science materials had been selected prior to the inception of CAMS, all the seventh-grade modules and most of the sixth- and eighth-grade modules selected were common to all of the partner districts.

Focus, Goals, and Plans for the CAMS Work

Whereas MISE's prior work had addressed science education across grades K–8, the MSP proposal focused entirely on middle school teachers. Many middle school teachers had only elementary level content and pedagogical knowledge in science. District and building-level administrators in the partner districts recognized that CAMS would provide extensive professional development to teachers that the districts would not be able to offer on their own. Partner districts also looked forward to working together to share knowledge and resources.

Baseline data on classroom instruction gathered as CAMS began indicated a strong need for improvement in science instruction. On the positive side, more than 80% of middle school science teachers in the partner districts reported using instructional practices consistent with reform-oriented instruction. However, observations by researchers indicated that even though teachers were using inquiry-based materials and incorporating investigations into science instruction, their lessons lacked intellectual rigor, teacher questioning that enhanced the development of student understanding, and appropriate sense-making.

CAMS set as its overall goal the enhancement of student learning by providing challenging, high quality science instructional programs in all Consortium classrooms. This report focuses on those aspects that were aimed at deepening and strengthening the disciplinary and pedagogical content knowledge of middle school science teachers and at helping science teachers transfer their new knowledge and skills to classroom practice:

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

Other specific goals of CAMS included developing professional capacity through new teacher preparation and a Master's degree for in-service teachers, building parent and community support, and improving mathematics education.

Curriculum Frameworks and Instructional Materials

CAMS partners were to work together during Year One of the MSP to identify desired instructional outcomes and organize them into science frameworks aligned with both state content standards and the policies of the partner school districts. The purpose of the frameworks was to make explicit to teachers the core concepts addressed in their instructional materials, as well as their alignment to state standards. It was further envisioned that the frameworks would be used to guide teachers in planning instruction and to guide district curriculum leaders in aligning and articulating instruction across the K–12 spectrum.

The frameworks would inform selection of standards-based instructional materials for science in all partner districts to help ensure content-rich, challenging courses for all students. CAMS planned to use a model such as the Analyzing Instructional Materials (AIM)[2] process developed by the Biological Sciences Curriculum Study to ensure the establishment of criteria for effective instructional materials, the use of evidenced-based processes for reviewing materials, and the development of teacher expertise in using the model. Although the districts already had many materials in common, different modules had been selected to address the state's sixth-grade physical science and eighth-grade life science standards. Professional development would be provided for local district stakeholders to assess materials addressing these two standards and make recommendations to their respective school boards. The plan was that after curriculum frameworks were developed, all subsequent new instructional materials would be selected and implemented jointly as a Consortium.

Professional Development Capacity

In order to offer Curriculum Workshops, CAMS needed to develop a cadre of professional development providers. Curriculum Workshops were to be led by instructional teams (ITs) composed of people with expertise in science content and in teaching. A Consortium committee would select IT members who had strong backgrounds in science, were committed to inquiry-

[2] AIM is an evidence-based process for analyzing instructional materials. It was designed as a professional development experience to support curriculum implementation, examining the characteristics of standards-based materials to determine the extent to which they meet district needs. Steps in the process are: (1) identify criteria (in terms of content, the work students do, assessment, and the work teachers do); (2) gather evidence; (3) analyze evidence and apply rubric; (4) score components; (5) summarize results; (6) conduct pilot and collect student work; and (7) select materials. Additional information on the AIM process can be found on the Biological Sciences Curriculum Study (BSCS) website: http://www.bscs.org/professionaldevelopment/pdservices/aim.html

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based instruction, were effective with students, had previously worked with adult learners, were viewed as leaders by their colleagues, and had good interpersonal skills.

ITs for Curriculum Workshops were to consist of two teachers familiar with the instructional materials and a science content expert. (Content experts included Kean University science faculty, MISE staff members, high school science teachers, and experienced middle school teachers.) Teams would pair new and veteran teachers to help increase capacity and groom new leadership. Project leaders intended that IT members would receive a minimum of 26 hours of professional development each year of the project, including a 20-hour retreat to be conducted jointly with the mathematics ITs during the summer or school year, and at least one additional planning day during the year for each team. IT retreats would focus on designing and delivering professional development, using inquiry to deepen science content understanding, assessing inquiry-based learning, integrating disciplines, and working with adult learners. Time would be provided for IT members to design the Curriculum Workshops, with guidance from MISE staff and experienced IT members.

Curriculum Workshops

The CAMS science Curriculum Workshops were based on the peer teacher workshop model developed and implemented during the LSC grant period. These four-day workshops would focus on building teachers' content understanding while equipping them to implement standards-based instructional materials.

The Consortium proposed basing the Curriculum Workshops on selected units for each of grades 6–8. Curriculum Workshops would be offered for at least one unit per grade level each summer, with follow-up sessions during the school year. Teachers from the partner districts would be provided with release time to participate in the follow-up sessions. In some cases, depending on district guidelines governing professional development, teachers would receive professional development hours or would be paid for their time while participating in the workshops.

In-Class Coaching

In-class support would be provided by four science coaches, a staffing level that CAMS leaders hoped the school districts would be able to maintain once MSP funding ended. Each coach would provide non-evaluative, content-based coaching for teachers in grades 6–8 across the four CAMS school districts. Coaching would focus on promoting quality instructional strategies and reflective practice. Depending on the needs and interests of the individual teacher, it would include weekly consultations, model lessons, co-teaching, non-evaluative observations, and/or collaborative review of student work. The CAMS coaching model emphasized supporting and strengthening effective instruction rather than providing remediation for poorly performing teachers or serving as a substitute for the classroom teacher.

Preparation for coaches would begin with a 40-hour coaching institute to address effective coaching and mentoring strategies and develop leadership skills. The overall emphasis would be on using the coaching relationship to deepen science content understanding. Coaches were to learn strategies to support new teachers, work with diverse learners, and facilitate study groups. Monthly follow-up sessions for coaches would allow them to share strategies, examine data about effectiveness, and review research articles relative to their support role.

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The plan was for each coach to work with 12 classroom teachers in four schools at any given time, focusing initial efforts on new teachers and their mentors. CAMS leaders intended for coaches to meet weekly with each teacher, spending one day per week at each of their four schools. In addition, coaches would share responsibility for leading study groups.

District Administrators

While the primary focus of CAMS was on teacher professional development, project leaders were well aware of the critical role played by district and, even more importantly, school administrators in supporting teachers as they worked to improve science education. It was also recognized that developing the capacity and support of administrators would be critical to sustainability of the work beyond MSP funding.

Project plans called for MISE staff, along with consultants, to conduct a periodic Administrators' Institute that would involve superintendents, central office staff, district-wide directors and supervisors, principals, and vice principals. The Institute would be designed to equip administrators to support and lead instructional improvement. It would include sessions on inquiry-based science, standards, K–12 articulation of concepts, developing appropriate observation and evaluation tools, instructional leadership strategies, classroom and school walk-throughs, data management, and awareness of CAMS activities. Administrators would also work together to develop strategies for monitoring and guiding the use of curriculum frameworks and instructional materials.

Support from key leaders would also be secured through their inclusion and regular participation on various management and implementation committees formed to oversee the CAMS work. For instance, the Consortium Management and Oversight Committee (C-MOC) and Consortium Planning and Implementation Team (C-PIT) would each include members representing the districts in addition to MISE staff and faculty from Kean University. Internal Planning and Implementation Teams (I-PIT) included principals, teachers, and, in some instances, other stakeholders such as parents, students, or union representatives. Members of the C-PIT committee served as liaisons between the partnership-level teams and the district-level teams, keeping the I-PIT members informed about the work and involving them in decisions at the local level. This vertical communication pathway reinforced the CAMS vision, and engaged district and school stakeholders in the work of deepening teacher content knowledge.

CAMS in Action

Curriculum Frameworks and Instructional Materials: Aligning CAMS Work to State Expectations

A CAMS Frameworks and Instructional Materials Committee was formed to draft curriculum frameworks and to cross-reference them with the instructional materials being used across the Consortium. CAMS staff posted the framework correlations on the Consortium website. Although the plan had been to use the frameworks for planning at all levels of CAMS, they proved more useful in some settings than others. The frameworks were used by instructional teams as they planned Curriculum Workshops and by coaches in their own professional

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development sessions, but they were not heavily utilized by teachers. The use of the frameworks at the district level varied, with one district adopting the frameworks and correlations with state standards as district curriculum guides, another district using them to guide teachers writing curriculum documents, and the remaining districts using them little or not at all.

The adoption of common science instructional materials had largely been accomplished before CAMS began. In Year Two of the project, a group of 31 science teachers, science curriculum leaders, and professional development leaders used the AIM process to select materials to address the two state standards for which they did not have common materials. A common sixth-grade physical science module was selected, but based on the evidence of districts' needs, two different eighth-grade modules were adopted to address the state's life sciences standard.

Content-Focused Professional Development: Building Instructional Team Capacity

The first step in implementing the Curriculum Workshops was to identify and prepare the instructional teams (ITs) that would design and deliver the workshops. As planned, ITs included a science content specialist and two teachers who had experience with the science module that would be the focus of a given Curriculum Workshop. Because of MISE's ten-year partnership with Linden and Rahway, these two districts had a number of workshop leaders with considerable experience providing content-based professional development. Consistent with the project design, teams often paired new and veteran teachers in order to build capacity.

Using the model that was implemented successfully during the LSC, professional development for IT members was provided by MISE staff, Kean University faculty, experienced IT members, and other educational experts. Typically, a one-day introductory retreat was held for new IT members, followed by a two-day retreat for all IT members. The introductory retreat for new IT members provided an in-depth introduction to inquiry, design of professional development, effective instructional strategies, and specific strategies for workshop design and delivery.

The two-day retreat had two goals: (1) to equip the ITs with the knowledge and skills necessary to provide high-quality professional development for CAMS teachers and (2) to provide IT teams with opportunities and support to plan their workshops. During the retreats, facilitators modeled and explicitly addressed various elements of effective professional development. The retreats included large group sessions for all IT members to experience and discuss effective professional development practices, and small group opportunities for ITs to begin planning their Curriculum Workshops. The small groups also met following the retreat, typically once or twice, to complete planning for the Curriculum Workshops. MISE staff worked with these ITs to ensure consistency across workshop planning and delivery.

From the beginning, the two main goals of the science Curriculum Workshops were to prepare teachers to use the science modules that were the focus of the workshop and to deepen teacher knowledge of important science concepts that were embedded in the modules. As CAMS evolved, greater emphasis was placed in workshops on deeper examination of science content rather than the logistics of teaching the materials. As a result, the IT retreats came to focus on preparing ITs to deepen teachers' understanding of how students think about important science concepts, help teachers understand how important science concepts were taught in the materials, and prepare teachers to develop student understanding of important science concepts.

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As professional development for ITs began to delve more deeply into science content, the need arose to align their preparation with the subject-grade range of the Curriculum Workshops the IT would be designing and implementing. Midway through the project, the joint IT retreats for mathematics and science teachers were replaced with separate retreats—a move that met with the approval of IT members.

Later in the project, the focus for IT members' professional development included tools to be incorporated into Curriculum Workshops in order to strengthen teachers' disciplinary and pedagogical content knowledge. These tools included:

- Curriculum Topic Study (CTS)—a tool to help educators deepen their understanding of important science and mathematics topics by examining content, state and national standards, research on students' ideas, and opportunities for students to learn science and mathematics through improved teacher practice;

- Formative assessment tools and strategies, including an ETS program called *Keeping Learning on Track* that helps teachers incorporate "assessment for learning" into their classrooms; and

- BSCS 5E Learning Cycle, a teaching sequence that includes Engagement, Exploration, Explanation, Elaboration, and Evaluation.

Curriculum Workshops: Building Teacher Content Knowledge

Curriculum Workshops were offered each summer of the project to all middle school science teachers in the partner districts—although not all teachers participated. The workshops were four days in length, with two follow-up days provided during the school year. The focus of each Curriculum Workshop was a specific science module that had been adopted by the partner districts as part of the science curriculum. Typically, one Curriculum Workshop was offered at each grade level each summer. IT members were paid $2,000 each for developing and facilitating the four-day workshop, funded by MISE, and participants were paid by their districts according to union contracts. The follow-up days were conducted after school or on regularly scheduled professional development days, again with teachers paid according to union contracts.

The first summer, teachers of all levels of experience attended the Curriculum Workshops. Participants were generally positive about the workshop experience, but noted a need to differentiate instruction based on teacher experience. Consequently, in subsequent years an introductory workshop was offered to teachers who were new to the materials to help them become familiar with the science modules. The Curriculum Workshops were then targeted at teachers who had taught the modules at least once enabling instructional teams to engage teachers in a more in-depth examination of the content of the modules.

Initially, the focus of the Curriculum Workshops was on use of the materials, using CAMS assessment data to fine-tune teachers' use of the materials, and the content contained within the materials. Over time, evidence indicated that teachers continued to struggle with science concepts during the workshops and classroom observations revealed that teachers found it

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difficult to engage students intellectually with the content in their classrooms. In response, CAMS leaders continued to revise the Curriculum Workshops to try to deepen not only teachers' understanding of the concepts, but also their pedagogical content knowledge. The timing of the school-year follow-up sessions was adjusted to coincide with the implementation of the particular units in order to help teachers transfer what they had learned to classroom practice.

CAMS leaders continued to refine the Curriculum Workshops over the course of the project in an ongoing effort to help teachers better understand the content within the science modules—and how to teach it more effectively. The tools introduced to ITs, Curriculum Topic Study, formative assessment, and the BSCS 5E Learning Cycle, were incorporated into the workshops. The goal was to increase teacher awareness of the concepts in the materials and to relate the materials to student learning.

It was hoped that the Curriculum Workshops' focus on science concepts within the context of instructional materials, coupled with the tools, would deepen teacher understanding of key concepts, help them engage students in inquiry-based instruction around those concepts, and enable them to assess student understanding and adapt instruction accordingly.

In-Class Coaching: Building Capacity for Classroom Support

The CAMS coaching component was included to provide on-going support for classroom teachers. Like the training for Curriculum Workshop ITs, professional development for coaches initially focused on general coaching strategies and logistics and emphasized science content and pedagogy. CAMS coaches began their training with an intensive, two-week coaching institute. Three days of the institute were provided by the New Teacher Center at the University of California at Santa Cruz, centered on coaching skills, strategies, and tools. An additional two days focused on the science curriculum modules that were being used in all four districts. Time was also devoted to coaching logistics, such as school assignments and scheduling.

Coaches were assigned to schools following the institute, but continued to meet weekly for full-day "coaching forums" to discuss professional literature and videotapes of coaching, role-play, discuss coaching tools and protocols, clarify their role, and share their experiences in the schools. By the end of Year Two, as coaches became more familiar and comfortable with their roles, project leaders reflected on the strengths and weaknesses of the coaching component. One need they identified was for more content-specific coaching strategies to help coaches diagnose instructional problems and guide teachers in reflection and planning around the content they were teaching. Consequently, a comprehensive professional development plan for coaches was created, reducing the frequency of coaching forums to once a month and offering content-focused sessions twice a month. In these content sessions, MISE staff and external content experts engaged coaches in content-specific activities designed to increase their content knowledge and better equip them to assist teachers.

Over time, the focus of content sessions for coaches became more aligned with other initiatives within CAMS, such as the Curriculum Workshops; a project-wide focus on formative assessment; and examining student data, such as the CAMS assessment results, to make instructional decisions. Coaches received training on the same set of tools that ITs would be

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introducing to teachers in Curriculum Workshops. This alignment was to ensure that coaches were prepared to help teachers transfer what they were learning to the classroom.

Coaches' work in the schools mirrored the changes in their professional development. Coaches initially focused on defining their work and establishing trust and rapport within the schools. Later, as coaches became more comfortable with their roles, coaches' training and their work in schools shifted to a stronger focus on helping develop teachers' disciplinary and pedagogical content knowledge. During Year Four, project leaders worked to align coaches' work more tightly with the professional development teachers were receiving so that they could assist in helping teachers transfer what they were learning to classroom practice. A frequent focus of coaches' work with teachers was assisting them with planning and/or implementation of the lesson teachers were teaching the day the coach visited the school. These conferences usually involved discussions of the lesson's content, as well as use of materials and appropriate pedagogy. Coaches noted that teachers' greatest need was strengthening their understanding of the content they were teaching; consequently, content continued to be the most frequent focus of their interactions with teachers. Group meetings with teachers often focused on similar issues, i.e., lesson planning that included discussions of content, materials, and pedagogy.

Just as CAMS leaders used feedback from coaches and evidence of their impact to adjust coaches' training and focus, these data informed decisions about the structure of coaches' work as well. Coaches logged their activities, and analysis of the coaching logs revealed that attending their own professional development and managing the logistics of the work resulted in coaches working with fewer teachers and spending less time on direct classroom support than originally anticipated. Modifications to the program, beginning early in CAMS and continuing in later years, led to increases in the amount of time coaches were able to devote to direct work with teachers either one-on-one or in small groups. In addition, the number of teachers assigned to each coach was reduced over time in order to increase the time coaches could spend with individual teachers, and coaches increasingly focused their efforts on working with teachers who had attended CAMS professional development.

District Administrators: Building Capacity and Support

The main vehicle for building the capacity of administrators to support science education improvement was the Administrators' Institute, which was offered annually throughout the project period. Each of the Institutes was an overnight retreat; topic areas were aligned with the professional development being delivered that same year to ITs who led Curriculum Workshops, to coaches, and to the teachers themselves during Curriculum Workshops. Administrators learned about science instruction through participation in inquiry-based science investigations and by viewing and discussing videotapes of science lessons. Curriculum topic study (CTS) was used to examine student work and identify common student misconceptions in a "study group" setting. Administrators learned how to use CAMS student assessment data as a tool to inform instruction, much as teachers did. These activities familiarized administrators with CAMS resources in their schools and helped them develop a deeper understanding of what "good science teaching" looks like, which they could put to use in observing teachers and providing constructive feedback. In later years, the Institute came to include time at the end to help administrators plan ways to apply their knowledge when they returned to their schools.

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Over the course of CAMS, principals reported growth in their knowledge of and support for inquiry-based science instruction. Attendance at the Institute increased over the years, and administrators gave the Institute positive overall reviews.

In addition to the Administrators' Institute, the engagement of district administrators was encouraged by membership on CAMS committees. District superintendents were members of the project's oversight committee (C-MOC), which focused on vision and planning for the project and included deans and department chairs from Kean University in addition to MISE staff. The consortium-wide committee tasked with implementation of the vision, C-PIT, included MISE staff, Kean University faculty members, and administrators from the districts. Over time, the C-MOC committee deliberately increased the decision-making responsibilities of the C-PIT committee in order to develop leadership capacity within the districts.

Key Factors in the Implementation of CAMS

The CAMS MSP built on 10 years of work by MISE to improve science education. This prior worked helped project leaders foresee many issues and obstacles, and to design a powerful professional development model for teachers that included intensive professional development focused around instructional materials, follow-up sessions during the school year, and in-class support. Recognizing the key role played by administrators in supporting reform, the project also built in ongoing professional development for administrators. The project's strong emphasis on developing teachers' science content knowledge was based on increasing evidence that teachers needed to understand the content and how to teach it before they could effectively facilitate inquiry-based learning for students.

Feedback mechanisms built into the project provided important information that helped project leaders continually refine for the projects work with administrators, ITs, science coaches, and teachers to move closer to the project goal of providing all middle school students with challenging, standards-based science learning experiences. This feedback guided the project toward greater coherence over the five-year period so that all professional development activities were aligned, helping to ensure that all stakeholders shared a common vision of, and set of tools and strategies for, science education.

As project leaders continually refined their work, they also built in mechanisms for transitioning leadership of the reform effort to district partners. Factors that appeared key to the CAMS MSP experience are identified below.

- MISE's long-term investment and the partners' commitment to shared decision-making led to investment in the project and engagement in Consortium-level planning.
- Using evidence to identify stakeholders' priorities and attending to those priorities encouraged buy-in from K–12 educators and school and district administrators.
- Aligning instructional materials, student assessments, professional development, classroom coaching, and administrator development built and sustained a common language and vision.

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- Feedback mechanisms provided information for refining professional development and in-class support to better meet project goals.
- Transition strategies and capacity-building were planned from the outset of the project to enable districts to carry the CAMS vision forward beyond the end of the funding period.

MISE's long-term investment and the partners' commitment to shared decision-making led to investment in the project and engagement in Consortium-level planning.
CAMS created a partnership among multiple, complex organizations, each of which had goals and structures specific to its mission. Progress towards the CAMS goals was dependent on the ability of the Consortium to develop a working relationship that was beneficial to each partner, building on the capabilities and resources and addressing the needs that each partner brought to the table. Consortium members reported that communication among partners was generally effective and decision-making was shared among them.

By the end of the MSP funding period, district partners indicated that there was a high degree of cooperation among the districts. The collaboration extended beyond the joint participation in CAMS professional development to a sense of shared resources, as indicated by the statements of key stakeholders:

> *I think there has been a spirit of cooperation. We have gotten even closer in collaboration, assisting one another. For example…if one district has something available there was a sharing. Not only a sharing of PD, but it has extended to smaller items like even supplies for our science and math programs…We don't have to work through C-PIT, we work director to director.* (C-PIT Member)

> *I think it really developed into a very fruitful and beneficial collaboration…like in the last meeting that we had it was really incredible to hear the partners, first of all, talk among themselves with a lot of respect and a lot of trust…and there was a lot of give and take, a lot of flexibility in people's, in individual's positions. There were some issues that arose because of coaching, you know, coverage and the future of coaching, and it was really clear that some of the initial ways that people started the discussion was using some very traditional kinds of positions like, "These are our funds, these people are ours, they should work only in our district." Well, by the end of the discussion…it was very interesting that what they came up with was: we benefit. We all benefit by sharing the coaches, and that's something that if this partnership hadn't existed for a period of five years, I don't think that we would have come to that type of conclusion during the discussion.* (C-MOC Member)

In contrast to the district partners, the partnership with Kean University did not fully develop as planned. Individual faculty members committed substantial time contributing to the Curriculum Workshops as facilitators, and some found their work with CAMS enabled them to make changes to their university instruction as well. However, several different Kean representatives served on CAMS committees over the life of the project, and they typically did not have the ability to make decisions for the multiple departments involved in CAMS.

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Using evidence to identify stakeholders' priorities and attending to those priorities encouraged buy-in from K–12 educators and school and district administrators.
Science content knowledge was at the forefront of CAMS throughout the five-year project period. Teachers consistently reported that the focus on content and the presence of content experts were among the most useful features of the Curriculum Workshops. As the project progressed, teachers' feedback was used to refine Curriculum Workshops and coaching goals to ensure that teachers' needs were being met. This attention to teacher feedback helped build support among teachers who attended workshops and received coaching.

CAMS leaders recognized that the intensive energy and resources invested in teacher professional development were unlikely to lead to systemic change unless administrators understood and supported the CAMS vision. Annual administrators' institutes helped increase the awareness and knowledge of district and school administrators about what effective science instruction looks like in the classroom, and how they could provide instructional leadership to support the improvement of science education. By coordinating the content of Administrator Institutes with the professional development teachers received, CAMS also helped ensure that administrators understood what they were seeing in the classroom and could provide support as teachers used tools and resources provided by CAMS.

Membership on Consortium-level committees was structured to meet the needs of key stake-holders in each institution. Top-level district and university leaders serving on the C-MOC engaged in vision and goal setting. District staff and university faculty serving on the C-PIT met more frequently and dealt with implementation issues. A district administrator who served on the project management committee described how information shared at committee meetings made districts' leaders more accountable for ensuring implementation in their own districts:

> *They came back with data about who attended the workshops so you had a sense of needing to take ownership of your own [staff] participating and who was there and what was going on… you had a sense of, were we fulfilling our part of the commitment? If not, you went back and said, "All right, step it up and do this."*

Aligning instructional materials, student assessments, professional development, classroom coaching, and administrator development built and sustained a common language and vision.
A strong feature of CAMS was that the professional development provided to all of the key players was aligned—even more so as the project progressed. The result was that in the last few years of CAMS, the professional development that was offered to administrators, instructional teams, science coaches, and teachers covered the same science concepts, materials, and resources. Thus, all stakeholders would understand (for instance) the nature of a curriculum topic study on a key science concept and impacts of the BSCS 5E Learning Cycle on classroom instruction. This coherence helped build and sustain a common language and vision across and within partner schools and districts.

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Feedback mechanisms provided information for refining professional development and in-class support to better meet project goals.
Project leaders used feedback from both participants and external evaluators to continually assess the effectiveness of their efforts to deepen teachers' disciplinary and pedagogical content knowledge in ways that translated to classroom practice, and to refine professional development accordingly. The result was that the project's approach to deepening teacher content knowledge became more focused and clearly articulated over time.

While keeping the goal of deepening teacher content knowledge at the forefront, project leaders learned along the way that in order to delve deeply into science content during professional development, teachers, coaches, and instructional teams must first learn to manage logistical or practical issues they would confront in their initial attempts to do this new work. As a result, the project began offering tiered professional development in all aspects of its work. Instructional team members who had not facilitated Curriculum Workshops participated first in an introductory session before joining other instructional team members in the retreat that would focus more strongly on content issues. Eventually, instructional team retreats included separate sessions for mathematics and science teams in order to provide opportunities to explore the content more fully. Coaching forums were also separated into general and content-focused sessions so that coaches could learn to manage logistics and general coaching issues but also explore how they could provide effective, science-focused coaching to teachers. Within the Curriculum Workshops, as well, teachers who had never used the instructional materials participated in an introductory session to familiarize them with the science modules before participating in Curriculum Workshops that delved more deeply into the content of the modules. These efforts to ensure that instructional team members, coaches, and teachers were comfortable with the logistics and materials they would be using before engaging them with the content helped ensure receptivity and readiness to explore more fully the science content that students would be learning, how to teach it effectively, and how to diagnose and respond to student misconceptions.

Transition strategies and capacity-building were planned from the outset of the project to enable districts to carry the CAMS vision forward beyond the end of the funding period.
No matter how well-designed a reform project may be, the work is unlikely to be sustained without a plan for school districts to take over the work when project funding ends. CAMS built in several transition strategies to ensure that districts had the capacity and infrastructure to continue with science education improvement after the MSP grant period. Including district administrators and teachers on planning committees, instructional teams, and as coaches helped build the capacity of district staff to carry on the work. Districts also made a commitment early on to take over the funding of coaching positions when MSP funding ran out, and they made good on that commitment. Similarly, ETS initially collected and analyzed the CAMS assessment data used by teachers and administrators. Over time, CAMS and MISE staff worked with district staff so that, in the final years of the project, districts took over the responsibility for collecting, analyzing, and reporting CAMS assessment data. All of these strategies contributed to the development of an infrastructure and capacity for the four partner districts to carry the CAMS vision forward.

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Likelihood of Lasting Impact for the CAMS MSP

A history of science education initiatives by MISE and a prior NSF grant had established a partnership between two of the CAMS districts and MISE. CAMS leaders planned for the sustainability of certain aspects of the work from the beginning, including a gradual shift in some responsibilities from MISE and ETS staff to district staff over the years. Following are insights, provided by CAMS leaders and participants, regarding their hopes for the work beyond the funding period and initial evidence of what will be sustained.

The Partnership

Looking towards the future, every district partner in CAMS will continue its work with MISE and with one another by becoming a part of the ongoing Partnership for Systemic Reform funded by MISE. Beginning in the summer of 2008, the partner organizations moved to the next phase of their work together, creating a Partnership that includes districts that have worked collaboratively with MISE since the LSC funding, in addition to the CAMS district partners.

The cornerstone of the Partnership's work is *The Academy for Leadership in Science Instruction* (the Academy). The Academy focuses on developing teams that are charged with creating school-based professional learning communities of administrators and teachers focused on improving science teaching and learning. The Academy will also have district teams to support the improvement of science education, developing policies and providing resources to facilitate the work of the school teams. In addition to the work of the Academy, professional development focused on the implementation of district-adopted science curriculum will be offered for teachers Partnership-wide, including curriculum-based workshops. The structure and work of the Academy is a direct result of the work done in the partnership, and evidence of the institutionalization of many of the initiatives provided by CAMS.

Although Partnership-wide meetings are less frequent than CAMS committee meetings once were, districts in the Partnership continue to collaborate in ways beyond the Academy. For instance, one district has developed a breeding program for organisms used in the life sciences, so that partner districts can purchase them directly from a local source instead of ordering them through a national supplier. The Linden district has invited teachers from adjacent partnership districts to attend its professional development offerings. As another example, Elizabeth district is paying for and offering Lenses on Learning to principals in partnering districts as well as principals of Elizabeth district schools.

Despite the likelihood of the continuation of several Consortium initiatives, district personnel named several barriers to lasting science education reform. These included: teacher turnover and shifting of personnel between grades and disciplines, administrator turnover, large class sizes, and not enough coaches to support all the teachers in need. One district liaison expressed specific concern that the work to improve science instruction in the district may not continue if s/he and other current personnel retire or move away. This district leader went on to cite MISE as the stabilizing force behind the reforms, stating:

> *It will have had a long-term effect—the fact that we are continuing in the partnership with Merck, that we are continuing to involve our staff as we move forward is really of*

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such value as well. That without that, perhaps we may lose some of it, but I don't think that we're going to lose anything…that what has become part of our culture now is just going to be reinforced all the time. It's a very positive culture. (C-MOC Member)

Professional Development and Classroom Support Capacity

One element of CAMS that provides sustained impact is the training provided to teachers who led the Curriculum Workshops. Many of these teacher-facilitators remain in the districts, and continue to lead curriculum-based workshops. The CAMS strategy of pairing experienced and new facilitators in the Workshops provides an ongoing pipeline of facilitators who are trained to lead high-quality professional development for the Partnership. The fact that CAMS selected coaches from each district and provided them with an intensive and ongoing training experience meant that the districts now have science leaders who can support district initiatives.

Teacher Content and Pedagogical Knowledge

Over the course of the MSP, CAMS conducted 17 Curriculum Workshops for science teachers, conducted common professional development days each spring, and provided coaching to teachers, with much of this professional development focused on content and pedagogical knowledge. Science teachers in CAMS districts addressed New Jersey's science standards using the designated instructional materials, incorporated hands-on activities into their science lessons, and increased collegial interactions in the classroom.

Engaging students with the science content in an intellectually rigorous manner was a major challenge. CAMS leaders increasingly targeted strategies for Curriculum Workshops and coaching to try to develop teachers' science content knowledge and pedagogical content knowledge more fully, and help them transfer their new learning to classroom practice. There was some evidence that CAMS was beginning to have success with these efforts. A large majority of science teachers in CAMS districts consistently reported that participation in Curriculum Workshops improved their teaching. Science teachers with even a small amount of CAMS professional development were significantly more likely to report using strategies that promote an investigative culture in their classrooms than were those with no CAMS professional development. One science teacher remarked:

I'm learning about organisms I never considered before. With book learning, I knew organisms exchange gases, but with this, I get to experience it. I go and research and look things up. I wouldn't have done that before [CAMS].

Similarly, teachers who had worked intensively with CAMS science coaches reported that coaches had influenced their pedagogy toward more inquiry-based approaches, helped them understand content better, and helped improve their skills in diagnosing how students think about the content. One teacher commented on how the combination of Curriculum Workshops and coaching helped her understand science concepts:

It's [CAMS] a big influence on me. Without the training, some of the concepts would still be foreign to me, and to have [the coach] to help me with that has been great.

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Administrative Support for Reform-Oriented Science Education
Professional development was conducted for school administrators to provide them with the knowledge and tools to support teachers in the implementation of high-quality science instruction. By the end of five years, the number of principals considering themselves knowledgeable about state standards in science had increased significantly, as did principals' sense of their preparedness to support teachers in the implementation of these standards. In addition, administrators sought to hire teachers whose vision of instruction was consistent with the project vision.

Closing Thoughts

The CAMS MSP was unique in the extent to which it built on prior work by an external entity (MISE) in supporting districts' science education reform. The fact that the leading external partner was affiliated with a major corporation contributed to the stability of science education in selected New Jersey school districts. Unencumbered by the staff turnover and competing priorities that confront urban school districts (and sometimes higher education institutions), MISE has been able to play the role of "keeper of the vision." MISE's prior work and commitment enabled CAMS to enter the project from a different starting point than many other MSPs. Project leaders were geared up from the start to focus in on developing middle school science teachers' disciplinary and pedagogical content knowledge in the context of existing instructional materials. At the same time, CAMS leaders never assumed that they had all of the answers, instead demonstrating that the Consortium was, itself, a learning organization. Feedback was welcomed and used effectively to continually refine the work. The result was a powerful professional development model that mirrors features of effective professional development identified in the research. Even so, evidence near the end of the MSP funding period indicated that there was still much work to be done in helping teachers transfer their new knowledge and skills to classroom practice. By continuing to build on lessons learned from the LSC and MSP projects, and with on-going support from MISE, the partner school districts are poised to move ever closer to the vision of providing challenging, standards-based science education for all middle school students.

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