RESEARCH REPORT

NATIONA L CENTER FOR IMPROVING STUD ENT LEARNING
AND ACHIEVEMENT IN MATHEMATICS AND SCIENCE

Scaling Up Innovative Practices in Mathematics and Science

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ABOUT THE CENTER

The National Center for Improving Student Learning and Achievement (NCISLA) in Mathematics and Science is a university-based research center focusing on K-12 mathematics and science education. Center researchers collaborate with schools and teachers to create and study instructional approaches that support and improve student understanding of mathematics and science. Through research and development, the Center has identified new professional development models and ways that schools can support teacher professional development and student learning. The Center's work was funded in part by the U.S. Department of Education, Office of Educational Research and Improvement, the Wisconsin Center for Education Research at the University of Wisconsin–Madison, and other institutions from 1995–2004.

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Scaling Up Innovative Practices in Mathematics and Science

Recommendations for reforming mathematics and science education in the United States call for fundamental changes both in the mathematics and science content taught in schools and in the approaches to teaching that content (American Association for the Advancement of Science, 1993; National Council of Teachers of Mathematics, 2000; National Research Council, 1996, 2001). For eight years, researchers at the National Center for Improving Student Learning and Achievement in Mathematics and Science worked with teachers and schools to create and study classrooms in which compelling new visions of mathematics and science are becoming the norm. (For more detail on Center work, see Romberg, Carpenter, & Dremock, in press.) In order to support teacher change and enable these visions to "travel" to other classrooms, Center researchers sought to understand how these classrooms function, what it takes to construct them, and how this knowledge can be used to create similar classrooms in new settings.

Since 1995, the Center has conducted an integrated program of research that has connected (a) the development of students' understanding of central mathematics and science content and practices, (b) classroom instruction and assessment that supports learning of those ideas with understanding, (c) professional development that fosters those kinds of instruction, and (d) organizational capacity that is required to support the professional development and emerging instructional practices. Since 2000, we have studied how to use this research to develop successful instructional practices in new settings.

In previous publications, we have discussed the ways primary and secondary students learn with understanding in particular content domains, as well as the instruction that fosters that understanding. (See *in Brief* publications and Center bibliography noted in sidebar, p. 2.) Here, we focus particularly on how to use what we have learned from our studies of students and teachers to develop similar innovative practices in new settings. Given the vision of learning and instruction that we embrace, these efforts present challenges, yet hold promise for student and teacher growth.

Challenges to Creating Innovative Practices

Visions of school mathematics and science that are based on learning with understanding entail fundamental changes in what Elmore (1996) called "the core of educational practice." Elmore conceptualized the "core" as including the ways teachers think about the nature of knowledge, as well as teachers' and students' roles in teaching and learning. He argued that the closer an innovation gets to that core, the less likely the innovation will influence teaching and learning on a large scale. In other words, Elmore argued that innovative practices that entail changing the core of educational practice do not tend to travel far beyond the situations in which they originate. On the other hand, real reform that addresses the changes in curriculum and teaching that are necessary to teach students meaningful mathematics and science requires changing the core of education practice. If we want to bring about changes that make a real difference in the learning of mathematics and science, we must find ways to extend the kind of innovative instruction that Center researchers have created and studied, in spite of the challenges faced in doing so.

Overview of the Report

The foundation for our work has been based on our conception of learning with understanding, so we start by clarifying what we mean by learning with understanding. We then focus on what teachers need to understand to foster it. Our research suggests that professional development and the organizational support required for successful professional development is key to creating classrooms in which students learn with understanding. In the third section, therefore, we discuss the nature of professional development that is required to engage teachers in developing instructional practices in which learning with understanding is the norm, and in the fourth section, we discuss the administrative support that is required to enable successful professional development. In the final section, we discuss how we conceive of using what we know about students, teachers, professional development, and organizational support to create successful practices in new settings. We argue that understanding how professional development has succeeded in one setting, does not provide a clear roadmap for implementing professional development in new settings and discuss why the knowledge and resources that we have developed through our research cannot simply be transported intact to new settings. We have, however, learned valuable lessons about what can and does travel, and we end this monograph by discussing how what we have learned can support developing successful practices in new settings.

TEACHING AND LEARNING IN MATHEMATICS AND SCIENCE CONTENT DOMAINS

Center research about students' learning — and teachers' instruction and professional development — in specific content domains is available on-line. A 50-page bibliography provides a list of Center researchers' publications and presentations. In addition, research briefs (*in Brief: K–12 Mathematics & Science Research & Implications*) feature —

Designing statistics instruction for middle school students (2004)

Algebraic skills and strategies for elementary teachers and students (2003)

Supporting professional development and teaching for understanding: Actions for administrators (2002)

Building a foundation for learning algebra in the elementary grades (2000)

High school students 'do' and learn science through scientific modeling (2000)

These publications and more can be found at —

www.wcer.wisc.edu/ncisla/

Learning With Understanding

The foundation for our work with both students and teachers has been based on our conception of learning with understanding. Building on earlier conceptions of understanding (Carpenter & Lehrer; 1999; Hiebert & Carpenter, 1992), we define understanding in terms of mental activity that contributes to the development of understanding rather than as a static attribute of an individual's knowledge. We propose that there are four related forms of mental activity from which mathematical and scientific understanding emerges: (a) constructing relationships, (b) extending and applying mathematical and scientific knowledge, (c) justifying and explaining generalizations and procedures, and (d) developing a sense of identity related to taking responsibility for making sense of mathematical and scientific knowledge. This framework applies not only to our analyses of children's thinking and learning, but also to our characterization of instruction and development of professional development programs that support learning with understanding. Although the four forms of mental activity in this framework are highly interrelated, for the sake of clarity we discuss each one separately and end this section with a look at understanding as a community activity.

Constructing Relationships

For students learning science or mathematics, new ideas take on meaning by the ways they are related to other ideas. Typically, children and adults construct meaning for a new idea or process by relating it to ideas or processes that they already understand. To provide a knowledge base to help teachers support students in making these connections, Center researchers worked to identify learning trajectories that portrayed the development of important mathematical and scientific ideas and practices. Our conceptual analysis of teacher professional development was based on the same fundamental conceptions we applied to students learning with understanding. We designed professional development to help teachers make connections between mathematical and scientific knowledge, knowledge of students' mathematical and scientific thinking, and instructional practices.

Extending and Applying Knowledge

Perhaps the most important feature of learning with understanding is that it is generative: When students or teachers acquire knowledge with understanding, they can apply that knowledge to learn new topics and solve unfamiliar problems. When students or teachers do not learn ideas or processes with understanding, they perceive each new topic as an isolated skill, and they cannot apply their skills to solve problems not explicitly taught to them. A fundamental assumption of our work was that for learning to be generative, knowledge must be acquired in ways that clarify *how that knowledge can be used*. In other words, students and teachers must be engaged in learning that involves the same generative processes that we expected them to apply to learn new ideas and solve unfamiliar problems in the future. Teachers in our professional development programs engaged in formulating and testing hypotheses about student thinking and the instructional practices that influence the development of that thinking (Franke, Carpenter, Levi, & Fennema, 2001).

Justifying and Explaining Generalizations and Procedures

Engaging in justification and explanation introduces students to the experience of professional mathematicians and scientists, who share and develop their ideas with colleagues through explanation and justification. Center researchers found that, working together, students could generate and validate new concepts and procedures, and, as they engaged in justifying and explaining these concepts and procedures, they developed an identity as learners — that they could generate mathematical and scientific ideas to make sense of science and mathematics, and that they could justify whether their ideas are valid (see sidebar). In much the same way, teachers involved in Center professional development examined the knowledge they were acquiring and how it was related to their conceptions and practices so that they could explain and justify their conceptions and practices. One of the critical features of Center professional development was that it fostered a *community* in which teachers could articulate and examine initial and emerging conceptions about mathematics, science, student thinking, and instructional practices.

Making Knowledge One's Own

Understanding involves the construction of knowledge by individuals through their own activity. One result of this activity is that students and teachers develop a personal investment in building knowledge. The learner comes to adopt a stance that knowledge is evolving and provisional: Knowledge is not simply something to be assimilated from someone else through listening, watching, and practicing. This does not mean that students cannot learn by listening to teachers or to other students, but they adapt what they hear to their own ends and do not simply accept what they hear because it is clearly articulated by an authority figure.

An overarching goal of our research and development efforts has been that students and teachers develop a predisposition to understand — and that they strive to understand because understanding is important to them. Teachers and students become reflective about the activities they engage in while learning or solving problems: They look for relationships among concepts that might give meaning to a new idea; they critically examine their existing knowledge as they look for and apply knowledge to develop new and more productive relationships, and they view learning as problem solving in which the goal is to extend their knowledge.

Understanding as a Community Activity

Learning with understanding generally has been thought of in terms of knowledge of individuals. Learning, however, often takes place in groups, and one of the benefits of thinking about understanding as *emerging* rather than static is that components of our analysis of learning with understanding can be applied to communities of learners as well as to individuals. In elementary and high school classrooms and in professional development communities, for example, activity often involved sharing strategies and ideas with the goal of developing within the community connections among the different strategies and ideas available to it. In our studies, the various communities were engaged in practices of generating knowledge. Conjectures were proposed, and members of a community often worked together to refine and validate those conjectures. Often a number of members of the community were involved in generating and refining a given conjecture. Artifacts adopted by the community became a basis for collective reflection and articulation of ideas. We saw classes and teacher communities adopt the stance that knowledge generation was a function of the community and that they did not have to depend on the teacher or professional development leader as the provider and arbitrator of what counted as knowledge.

What Do Teachers Need to Know to Teach for Understanding?

To help students learn mathematics or science with understanding, teachers need to know how to help students (a) connect knowledge they are learning to what they already know, (b) construct a coherent structure for the knowledge they are acquiring rather than learning a collection of isolated bits of information and disconnected skills, (c) engage students in inquiry and problem solving, and (d) take responsibility for validating their ideas and procedures. This kind of teaching requires that teachers have a coherent vision of (a) the structure of the mathematical or scientific ideas and practices they are teaching; (b) the conceptions, misconceptions, and problem-solving strategies that students are likely to bring to learning those ideas and where they are likely to struggle in learning them; (c) the learning trajectories that students are likely to follow; (d) the tasks and tools that are likely to provide a window into students' thinking and support their learning and problem solving; (e) the kinds of scaffolding that can support students to engage in sense making and problem solving; and (f) the class norms and activity structures that support learning.

This kind of knowledge cannot be embedded in curriculum materials or scripted into instructional routines. Teachers need flexible knowledge that they can adapt to their students and the demands of situations that arise in their classes. Acquiring this kind of knowledge requires new conceptions of professional development that go beyond traditional conceptions of teacher training.

Designing Professional Development to Foster Teaching for Understanding

Instruction that supports learning with understanding requires teachers to make ambitious and complex changes. Such changes require more than teachers being shown how to implement effective practices. Rather, as Little (1993) pointed out, teachers must engage in experimentation — "discover and develop practices that embody central values and principles" (p. 133) — and take on the role of what Giroux (1988) called the "teacher as intellectual." The proposed reforms require that teachers reinvent their practices in ways that reflect the reality that "teaching and learning are interdependent, not separate, functions. . . . [Teachers] are problem posers and problem-solvers; they are researchers, and they are intellectuals engaged in unraveling the process both for themselves and for [their students]" (Lieberman & Miller, 1990, p. 112). Achieving this vision requires the educational community to grapple with what it means for teachers to engage in ongoing (generative) learning and then how professional development and the development of professional community can contribute to that end. Building a basis for ongoing learning is one of the defining features of learning with understanding; thus, the Center's conceptual framework directly addresses the calls to reform expressed by others and provides a needed framework for teacher professional development, addressing both student learning and teachers' growth as learners and professionals.

Supporting Generativity

In the same way we think about students learning with understanding, we conceive of professional development in terms of teachers acquiring knowledge that can support inquiry and problem-solving and provide a basis for acquisition of new knowledge and continued growth. This requires new conceptions of teacher professional development that move beyond traditional training and coaching models. A fundamental assumption of Center research was that for professional growth to be generative, teachers must be engaged in learning that involves the same generative processes that they can apply to extend their knowledge to learn new ideas and solve unfamiliar problems in the future. Professional development must enable and support teacher inquiry (into subject matter, student learning, and teaching practice), so that teachers can adapt their practices in ways appropriate to the demands of subject matter and their students' learning (Cobb & McClain, 2001). Thus, we conceived of professional development that treats teachers as professionals who have the capacity to transform their teaching practices in a generative fashion, over time.

Connecting Knowledge

Our conception of teaching for understanding entails teachers forging connections among three bodies of knowledge: (a) the critical concepts, processes, and methods of inquiry and argumentation of the content they are teaching; (b) the ways their students' mathematical and scientific thinking develops; and (c) the nature and effects of their teaching practices. Different Center research teams investigated different hypotheses about fruitful ways to do this and came at this integration from different entry points. Some projects began by engaging teachers in the study of specific mathematics or science ideas (Kaput & Blanton, 1999; Rosebery & Warren, 2000). Some initially focused on student thinking and helped teachers construct explicit models of the development of students' science or mathematics thinking for specific topics (e.g., Carpenter & Levi, 1999). For others, discourse in classrooms was a critical feature (Rosebery & Warren, 1998, 1999). Although the projects started at different places and had different foci, the professional development programs all integrated student thinking, mathematics and science content, and instructional practice, which together gave this form of professional development its power.

Supporting Generalization and Justification

Our framework for learning with understanding implies that professional development should afford teachers opportunity to examine the knowledge they are acquiring and provide a community in which teachers examine, explain, and justify initial and emerging conceptions about mathematics, student thinking, and instructional practices.

Developing a Sense of Identity as a Professional and as a Learner

For teacher learning to become generative, professional development needs to be structured to support teachers in developing a sense of identity in which teachers assume a stance that they can generate knowledge as part of their regular instructional practice. As with generativity, a fundamental assumption of our work was that teachers are most likely to adopt this stance if professional development engages them in activity-generating knowledge as they examine and implement instructional practices. Not only should professional development be structured to enable teachers to organize and focus their inquiry, but it should also — and more importantly — prepare teachers to actively engage in inquiry that provides a model *and an impetus* for their continued learning.

Supporting Generative Growth Through Learning With Understanding

Center researchers have documented that teacher learning can become generative when teachers participate in professional development designed to develop their understanding. In a longitudinal study spanning seven years, Center researchers studied a group of teachers who participated in a professional development program to determine what contributed to making teachers learning generative (Franke, Carpenter, Fennema, Ansell, & Behrend, 1998; Franke, Carpenter, Levi, & Fennema, 2001). The researchers found that teachers whose learning became generative perceived themselves as creators and elaborators of their own knowledge about children's mathematical thinking. They perceived that the knowledge they acquired in the professional development was something on which they could build and that they learned from classroom engagement with their own students. Teachers whose knowledge did not become generative, on the other hand, tended to see what they gained from the professional development program as a fixed body of knowledge that they learned from experts. Generative teachers imposed structure on their knowledge. This structure allowed these teachers to attend to and remember details of students' mathematical thinking in ways that provided a basis for the teachers to refine their general understanding of children's mathematical thinking. All of the generative teachers clearly reflected on their understanding of mathematics, children's mathematical thinking, and ways their own instructional practices could help them to better understand and assist their students' learning of mathematics. The teachers also were very articulate in expressing their ideas about their conceptions and practices and the relations among them.

This study and the professional development programs and research conducted by other Center teams demonstrate that professional development can sow the seeds for teachers to engage in ongoing inquiry that strengthens their own mathematical and scientific understanding, their understanding of the development of their students' mathematical and scientific conceptions, and the instructional practices that foster that development and — importantly — show how that can be done.

Developing Professional Communities

Center research shows that teachers' inquiry does not survive well in isolation. The development of professional communities is critical to sustaining and generating teacher change, for many of the same reasons that mathematicians and scientists conduct their work within larger communities of inquiry. Such communities provide a climate for engaging in inquiry, sharing knowledge of student thinking, sharing norms for what counts as effective instruction and student achievement, and building social supports for managing uncertainty (Cobb, 1999; Cobb & McClain, 2001; Kaput & Blanton, 1999; Quiroz, 2001). Although strategies for creating communities to sustain long-term teacher professional development vary widely, Center research shows that these strategies all involve substantial restructuring of schooling to enhance collaboration between teachers and administrators. Such restructuring assists teachers in developing the resources necessary to conduct practical inquiry and in sharing the results with a larger community (Lehrer & Schauble, 2001, in press).

Requirements for School Organization That Supports Teaching for Understanding

Center researchers found that efforts to reform mathematics and science instruction must address three key organizational challenges: providing resources, aligning commitments, and sustaining and generating reform.

Providing Resources

Center research shows that schools require long-term commitments of resources for professional development in order to bring about fundamental and sustained changes in teaching practices. The key resources are material, human, and social resources. *Material resources* include money and anything money can buy, including physical materials, physical space, time, information, and the like. Material resources can be transferred among groups. *Human resources* are qualities of individuals such as knowledge, leadership, access to expertise, and the like. *Social resources* are the characteristics of groups of individuals. The evidence suggests that initiating and sustaining reform in a school require infusions of material and human resources from outside the school. Furthermore, these resources must contribute to the development of social resources in the school or professional development group. The findings provide direction for how to use limited resources and show that money by itself is not sufficient to fuel reform.

Support for these conclusions comes from qualitative analyses of resource allocation and use in Center collaborative studies (Gamoran, 2000; Gamoran, Anderson, Quiroz, Secada, Williams, & Ashmann, 2003). The data consist of observations of professional development, interviews with teachers who participated in the studies, and interviews with school and district administrators. The research illuminated the most important resources schools could appropriate and allocate, including time, outside expertise, and leadership roles.

From the perspective of teachers, time was the most critical material resource. Moreover, the most important use of time was for planning and learning with other teachers. Because their expertise and knowledge about student thinking in mathematics and science was limited, teachers also noted that expertise from outside the schools was essential to stimulating their investigations and learning. (When asked to whom they would go with questions about mathematics and science teaching, many indicated a member of the university research team who had been working with them and their colleagues.) University researchers affiliated with the collaborative studies served as key resources at all sites.

Center researchers also found that self-sustaining change (i.e., change that would endure beyond the life of the research and development project) requires a process that allows professional development to alter the nature and distribution of resources available in the school and district. When schools and districts restrict teachers to conventional roles, they prevent the school as an organization from enhancing its capacity in human and social resources. But schools and districts enhance their capacity for change if they promote leadership for teachers, recast administrative roles as facilitators rather than as managers, change the allocation of time during the school day, and provide materials and resources suitable to new teaching endeavors. When schools and districts allow new roles to emerge, they foster growth of new human and social resources. Schools and districts that force new initiatives to conform to existing arrays of resources, however, risk stifling potential change or marginalizing change agents.

Center research describes how professional development can build social relations among educators that can foster the emergence of new leadership. Following Newmann and Associates (1996), we identified the features of a teacher professional community in successful professional development programs. In such a community, teachers—

- *share a sense of purpose* in their attention to student thinking.
- *focus collectively on student learning*, as opposed to teachers' more common focus on administrative details and managing student behavior.
- *collaborate* on ways to improve their students' understanding of mathematics (in contrast to teachers' usual practice of working in isolation).
- *engage in reflective dialogue*, a conversation about the nature and practice of teaching.
- *make their own teaching practices public* rather than keeping their practice private and confined to the classroom.

Aligning Commitments

Teachers and administrators must cope with limited resources, respond to multiple demands on their time and energy, and negotiate diverse perspectives about mathematics and science instruction. Center research (Gamoran, 2000; Quiroz, 2001) indicates that to respond to these multiple demands, schools must appropriate, coordinate, and focus resources from three sources: (a) human and material resources from school and district administration, (b) human and material resources from people with expertise in learning and teaching mathematics and science for understanding, and (c) human, social, and material resources that teachers and administrators develop through their own efforts. The alignment and impact of these resources are elaborated in Gamoran et al. (2003).

Sustaining and Generating Reform

Sustaining teaching for understanding depends on leadership emerging within professional communities, a commitment to professional interdependence (rather than independence), and a commitment of human and material resources. The infusion of human and material resources must contribute to the development of social resources in ways that enable teachers to assume responsibility for leadership and that foster and maintain communities of inquiry aimed at understanding student thinking and designing instructional practices that build student understanding. When school personnel routinely evaluate, invent, and implement new practices, when those changes are motivated by and consistent with reform, and when teachers' professional communities and development are supported by the schools, change can be sustained. When, in contrast, teachers haphazardly acquire new practices with little or no community support or professional development opportunities, new practices tend to be brittle and prone to routinization. Those new practices at times might be abandoned altogether.

Creating Similar Classrooms in New Settings

The teaching approach and related professional development that we have described above are complex, and complex practices cannot, in principle, be simply codified and then handed over to others with the expectation that they will be enacted or replicated as intended. Traditional views of professional development presume that we can train teachers to faithfully enact instructional methods and strategies that have proven effective elsewhere. We have found that this is an inappropriate conception of professional development for teachers seeking to develop classroom practices that place students' reasoning at the center of instructional decision making. This kind of teaching requires professional development that supports teachers in developing the knowledge to adjust instruction to their students' needs and understandings. Instructional strategies that build on student reasoning cannot simply be transferred to a new setting because, by their very nature, such attuned instructional practices require refinement by teachers who have the intellectual framework and support to analyze, evaluate, and appropriately adjust practices based on student understanding.

Instruction that revolves around student reasoning involves ambiguity and uncertainty, and teachers need support in dealing with this uncertainty. Our ability to create and sustain classrooms that build on student reasoning depends on developing *professional teaching communities,* in which teachers support one another in dealing with uncertainty and rely on each other as resources as they engage in ongoing discussions of teaching and learning.

The long-term goal of reform (from the perspective of teacher professional development) can be framed as the creation of environments such that teaching, broadly construed, becomes a generative activity in which teachers routinely deepen their understanding of students' reasoning in specific mathematics and science domains. The critical elements required to accomplish this goal are that teachers make their classrooms sites for their own learning and that they have opportunity to participate in professional teaching communities that support teaching for understanding.

During the first five years of the Center, researchers engaged in developing professional teaching communities in a series of teaching experiments in schools. A central focus for the research for the last three years was to understand how to use what we had learned during the first five years to create professional teaching communities in new settings. Two questions propelled this endeavor: (a) What travels? and (b) What conditions are necessary for travel to occur?

What Travels?

The issue of what travels is not trivial. None of the Center research involved developing curriculum that could simply be implemented by a new group of teachers. All of the research-based reforms entail substantial professional development. Furthermore, the goals of the Center's professional development did not involve implementing carefully scripted instructional routines: Instruction that builds on student reasoning is a complex endeavor, and the professional development that supports that kind of teaching cannot be scripted or simply transported intact into a new environment. We do not, however, have to start from scratch in thinking about ways to construct professional teaching communities in new settings. Much of what we have learned can be used to support the development of new professional teaching communities. This includes (a) our analyses of mathematics and science content, (b) our analyses of the development of students' thinking related to this content, and (c) the ways we engaged teachers in inquiry about student thinking and teaching.

Specification and analyses of content. It is not productive to think about professional development without thinking about the content taught. The focus of the professional development of Center research was content specific and focused on long-term learning trajectories that aim at central mathematics and science ideas. Choice of content and analysis of the goals and learning trajectories have a critical impact on what we do in professional development: The most critical things that teachers need to learn revolve around content knowledge and the student learning trajectories specific to that knowledge. Learning specific content and learning how students learn that content were central to Center professional development. The kinds of tasks and tools researchers developed to foster learning were specific to the content. The sociomathematical norms (e.g., what counts as a different mathematical solution to a problem, what is an acceptable mathematical explanation) that researchers engaged teachers in thinking about involved specific content. Learning trajectories are dependent on specific content. Teachers learn about specific content, as a basis for hypothesizing learning trajectories, and teachers need specific content knowledge to understand and respond to students' learning.

Analyses of student thinking and related instructional supports. A second defining feature of the professional development we created was the focus on student reasoning, rather than on teachers' scripted performance. Center researchers documented regularities in what students do and how teachers respond to them. There are regularities in (a) student reasoning, (b) types of tasks that elicit that reasoning and support change, and (c) participation structures of classrooms. In each of the projects, researchers constructed models of the learning trajectories of basic mathematical or scientific ideas and the conditions under which those ideas develop. Although these models do not prescribe instructional practices, they provide a basis for understanding the teaching–learning process.

Engaging teachers in inquiry. A third critical feature was that teachers were using student work to engage in inquiry into student thinking. The processes surrounding the use of student knowledge is an important part of travel. Center researchers developed hypothetical learning trajectories for teacher learning in specific domains, which guided the selection of student work and influenced scaffolding of interactions related to that work.

Adapting resources. Center researchers determined that what travels is the process of using resources to support the emergence of successive patterns in students' mathematical or scientific reasoning. In particular, resources that support the development of new learning communities include (a) the fine-grained analyses of specific content domains that Center researchers have generated, (b) the analyses of hypothetical learning trajectories for these content domains, (c) specific tasks or types of tasks that provide a window on student reasoning and support the development of more advanced reasoning, (d) examples of participation structures and ways of interacting with students, (e) strategies and activities productive in engaging teachers in focusing on student reasoning. (For videotaped examples and information about teachers changing their practice based on their professional development, see Carpenter & Romberg, 2004; also see sidebar on p. 4.)

Although our research shows that the resources we developed can be used to support the development of professional teaching communities in new settings, we learned that the context in which the resources are used has a significant impact on how resources are used. The ways the resources are used in a new setting can look very different from the ways they were used in the setting in which they initially were studied. Thus, the resources themselves cannot simply be transported to a new school or district with the expectation that the teacher professional development process will replicate what occurred at other sites. The resources must be transformed or adapted to the constraints and affordances of new contexts. Travel entails supporting the development of professional teaching communities in a new educational context, not merely transporting practices in the hope that professional community will emerge.

What Is Necessary for Travel to Occur?

Center research not only provided insight into what travels but also into what is necessary for travel to occur, such that the work in new sites maintains fidelity to the guiding principles of the original work.

Engaging teachers in design practices. One critical feature for travel was the continuing involvement of teachers in design practices. There is a danger that the further the practices are removed from the initial design experiments, the less teachers are inclined to engage in such practices. Professional development itself was conceived as a design experiment set in the context of work in the professional development seminars, in teachers' classrooms, and in the professional lives of teachers. The goal was not to train teachers to implement instructional practices faithfully: Each new professional development site engaged in design experimentation, building on the design experiments conducted by Center researchers.

Travel occurs through people. A second observation about travel is that travel occurs through people in much the same way that groundbreaking work in science travels through the postdoctoral fellows engaged in the work in the laboratories in which the initial innovations occurred. Attempting to employ the resources and apply the conceptions of professional teaching communities developed in one site without direct connections to people who were involved in developing the conceptions and resources faces a low probability of success. This does not mean that only the creators of an innovation can successfully reconstitute it in a new setting, but that professional communities in new sites must have access to human resources with direct links back to the people who developed the resources and conceptions.

The same argument that we made about the futility of codifying and attempting to hand over instructional practices to teachers also applies to the practices of supporting teachers' learning. We found it crucial that the people who provide the links have not only engaged in implementing the instructional practices in classrooms, but they have also participated in the practices of supporting teachers' learning in a substantial manner. They need specific experience not only with the resources that support focusing on student reasoning in classrooms but also the strategies and activities that proved productive in engaging teachers in focusing on student reasoning.

The people working in the new sites might be a number of instantiations removed from the developers, but they need to be connected to the original work through a chain of successful communities of practice based on the original work and adaptations of it. This means that "scaling up" is not something that can be done overnight, but that professional communities can be expanded to reach large numbers of people through exponential growth.

Institutional support. Finally, in considering how professional development travels, it is necessary to take into account institutional contexts that might (or might not) support the goals of developing professional teaching communities. Teachers' instructional practices are profoundly influenced by the institutional constraints that they attempt to satisfy, the formal and informal sources of assistance on which they draw, and the materials and resources that they use in their classroom practice. It is important to take into account the specific institutional settings in which teachers develop and refine their instructional practices when negotiating an agenda with them.

In the current era of high-stakes testing and accountability, district and school administrators frequently respond to the pressures on them by attempting to monitor and regulate teachers' instructional practices rather than assisting them (a) to become instructional leaders; (b) to develop professional communities; or (c) to improve their understanding of content, students, and instructional practices. Working to bring about change in the institutional setting has to become part of the agenda of the professional teaching community, but our goal is not to propose that schools and districts should operate in narrowly specified ways. Rather, our goal is to clarify ways that the professional capacities of teachers and students' learning can be enhanced.

It is critical, however, that leaders who control resources come to see value in the professional teaching communities and the kinds of teaching and teacher learning that they can support. Minimally, school and district leaders eventually will need to (a) be flexible in their expectation about content coverage, (b) either establish a compelling vision in support of teaching for understanding or provide teachers with the authority to develop such visions, (c) share instructional leadership responsibilities such that leadership is organic rather than bureaucratic, and (d) manage inevitable conflicts within the school and district over curricula, resources, leadership, and the like. Ideally, school and district leaders eventually will support the collaboration of teachers to understand and build on their students' reasoning. Fostering leadership that supports rather than impedes the development of professional teaching communities is a critical element in travel.

Summary and Conclusions

Learning with understanding depends on building on what students know and their ways of thinking. Similarly, the nature of instruction and professional development that we have studied is based on placing students' reasoning at the center of instructional decision making. This not only represents a fundamental challenge to core educational practice, but it also represents a fundamental change in how we conceive of professional development and how it travels to new settings.

The work we have conducted in the last years of the Center has focused on the question of whether research-based instructional sequences of the sort that we tested and revised during the design experiments can serve as a primary means of supporting teachers' development of generative instructional practices. The key points to emphasize are that such sequences are justified in terms of (a) the trajectory of the students' mathematical and scientific learning and (b) the means by which that learning can be supported and organized. It is this trajectory that constitutes the conceptual backbone of the instructional sequences. Specific instructional activities can be modified yet remain faithful to the intent of the instructional activities — the learning of key mathematics and science ideas. This affords teachers considerable flexibility in that it is possible to adapt the sequences so that they can also be used, for example, to develop units integrating mathematics with science or social studies.

A rationale of this type, cast in terms of a learning trajectory, can be contrasted with the standard approach of using traditional experimental data to justify an instructional innovation. In the latter case, teachers know only that the innovation has proven effective elsewhere but do not have an understanding of the underlying ideas that would enable them to adapt the innovation to their own instructional settings. In contrast, a justification cast in terms of learning trajectories offers the possibility that teachers will be able to adapt, test, and modify the instructional sequences in their classrooms. To the extent that they do so, implementation becomes a process of idea-driven adaptation in which teachers cease to be mere consumers of instructional innovations developed by others and instead contribute to both the improvement of the sequences and the development of the local instructional theories that they embody.

Our findings about travel are based on assumptions about ways to conceive of travel, the nature of learning of teachers and students, norms for instruction, and what is important for students and teachers to learn. We have found that what travels – and can be sustainable — are patterns of reasoning and what teachers do with them, not the enactment of specific instructional activities. Rather than thinking of resources being adopted intact, we need to think in terms of adapting resources to the constraints and affordances of new communities. The Center's conception of the creation of innovative instructional programs in new settings challenges many traditional conceptions of professional development. Our research also challenges the notion that simple solutions will work effectively in the complex environment of the classroom and school. Our research, moreover, convinces us that fundamental reforms in mathematics and science learning and teaching are most likely to be achieved through (a) pursuing professional development based in teacher inquiry and student conceptual understanding and (b) travel focused on teacher generative learning and the fostering and support of teacher professional community.

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