RESEARCH INTO PRACTICE

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With this article, we begin a special section dedicated to the link between research and practice. This article by Loucks-Horsley and Matsumoto is focused on the influence of research into practice. We welcome your submissions for consideration for this special section. Use the normal submission processes, specifically indicating your desire for the manuscript to be considered for the Research Into Practice section. *- Editors -*

Research on Professional Development for Teachers of Mathematics and Science: The State of the Scene

In the recent standards-based zeal to improve learning and achievement for all students, professional development is viewed as central to educational reform (Elmore, 1996; National Commission on Teaching & America's Future [NCTAF], 1996; National Education Goals Panel, 1995). The reason for this is simple. The NCTAF report cited grim statistics that include the following:

- Annually, over 50,000 untrained people enter teaching on either emergency or substandard licenses.
- Nearly one fourth (23%) of all secondary teachers do not have even a college minor in their main teaching field. More than 30% of mathematics teachers fall into this category.
- More than half (56%) of high school students taking physical science courses, 21% in English, and 27% in mathematics courses are taught by teachers who do not have backgrounds in these fields.
- In high poverty schools and in lower track classes, the proportion of teachers inadequately prepared is even higher (pp. 15-16).

Clearly, we need more teachers who are well prepared to teach to more challenging standards and who can help all students learn; the cry for more and better professional development is unanimous. At the same time, professional development is being subjected to increasing scrutiny. There are many who believe that the monies allocated to professional development are not a worthwhile investment unless targeted toward improving student achievement (Dozier, 1998; Education Commission of the States [ECS], 1997; Guskey, 1998; Killion, 1998a; Riley, 1998). It is tempting, therefore, in a review of the research on professional development, to focus only on those studies that link or attempt to link it to student learning. Such a review would address the question, what is the nature of professional development that brings "return on the investment?"

There are several reasons, however, why we have chosen not to limit this review to studies that link professional development to student learning. First, there is relatively little research addressing this connection directly, due in part to the difficulty in establishing a clear connection between the two.

To illustrate the complexities in establishing clear lines between professional development and student learning, Guskey and Sparks (1996) used a model that organizes the many components, roles, and relationships within a school's "sphere of influence." Their model proposed that student learning outcomes are improved through the complex relationships among quality staff development and administrators', teachers', and parents' knowledge and practices and a number of factors influencing each of these components. These authors concluded that establishing a clear link between professional development and improved student learning — if one actually can be made — requires substantial research and evaluation that carefully account for the various contributions that each factor makes to the desired outcome.

Second, research on or evaluation of professional development usually does not assess student learning. Instead, studies define effectiveness as different kinds of teacher engagement (e.g., attendance at workshops) or, at best, teacher change (e.g., change in knowledge or classroom practice). School districts and states often

do not distinguish between "spending" and "investing" in professional development (ECS, 1997).

More often, they "evaluate for compliance rather than for effectiveness and do not evaluate the connection between the dollars they spend, the programs they purchase and results they get" (ECS, 1997, p. 7). It is both expensive and difficult to design and conduct evaluations that can isolate and measure the specific effects of professional development on student achievement (Frechtling, Sharp, Carey, & Vaden-Kiernan, 1995; Killion, 1998b).

This problem was striking in the review of 450 projects conducted by the Middle Grades Initiative of the National Staff Development Council, which found that more than 90% had no measurement of student achievement, improved or otherwise (Killion, 1998b). If, in our effort to synthesize the research, we reviewed only studies linking professional development and student learning, we would be forced to eliminate large numbers of studies that responded to other important questions, such as what contributes to teacher learning, how teachers make changes in their practice, and what factors support change.

Third, connected to the first reason, rather than moving directly from professional development to student learning, we would argue that more needs to be understood about the intricate connections between teacher learning and student learning. In the push to implement both content and student performance standards, it is apparent that teacher learning is critical in helping instruction move beyond mechanistic implementation to maximize student learning. Exactly what teachers need to know to do so, and how they need to learn, are critical pieces of the picture that results in student learning.

The fourth reason we chose to examine more research than that linking professional development and student learning is the fact that a number of different paths of research on "what works" in professional development appear to be converging. A review of research in a number of different areas — among them, learning in general, teacher learning and development, implementation and change, organization development, and policy — suggests that a number of factors leading to successful teacher learning have been clearly identified. The review (which is the focus of this article) also points out where more research is needed.

Finally, we determined that fixating on student learning as the only important outcome for professional development ignores other critical outcomes, for example, changes in teacher knowledge and practice, implementation of new programs, changes in school culture, and development of teachers' leadership abilities. These outcomes are critically important to the broader goal of national reform in science and mathematics education.

We have, therefore, chosen not to limit our review to those studies linking professional development to student learning. We will, however, point out where studies exist that make strong links between the two.

A Model to Organize the Research

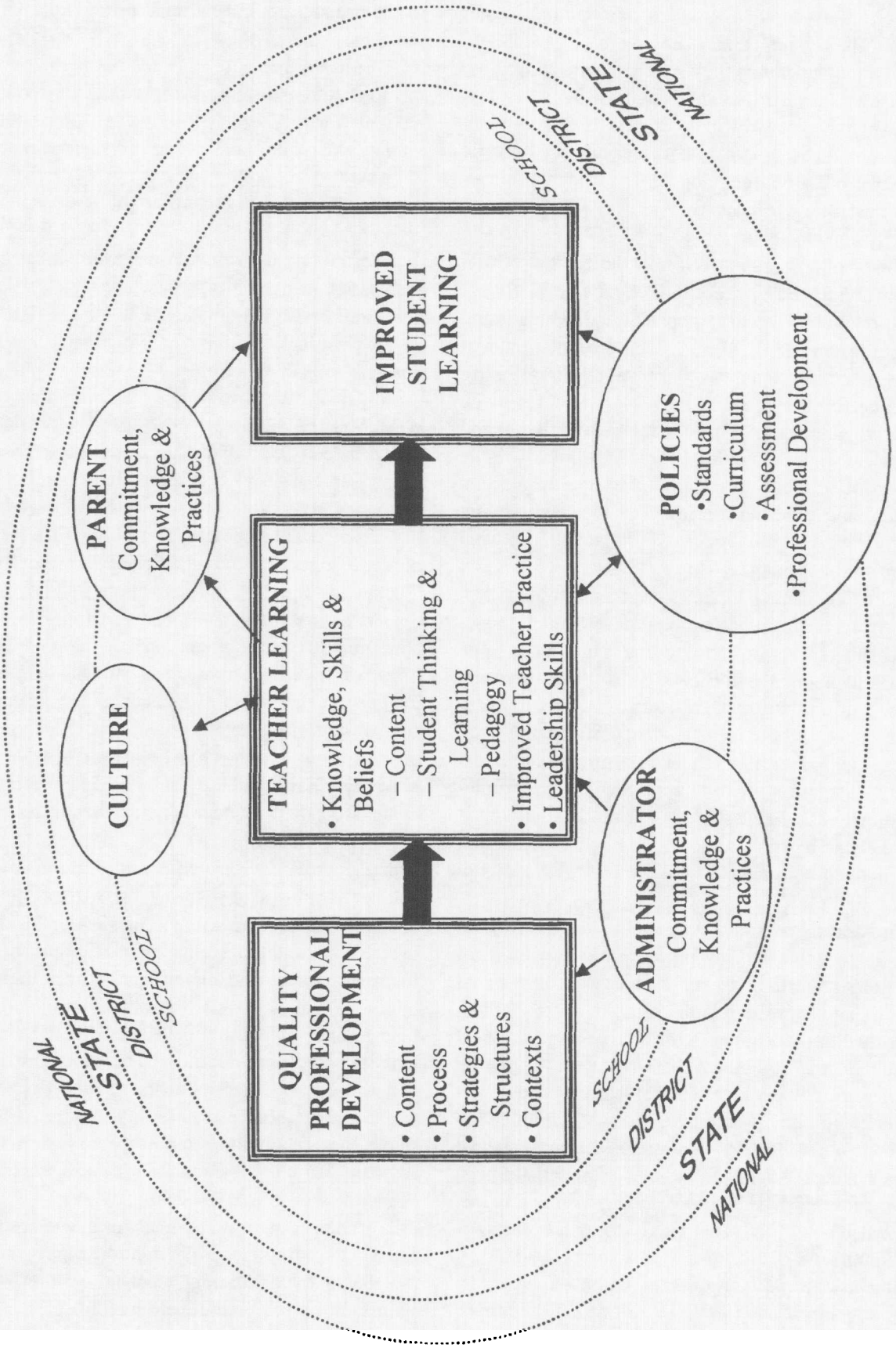
Organizing the research on professional development is a challenge, since the research base is so large and since researchers ask a wide variety of questions. In this review, we looked for patterns or trends that indicate consensus about which characteristics or components of professional development sessions, programs, or initiatives are effective, however "effective" was defined in the study. Indeed, we found many such characteristics and components in a review of research on learning, teacher learning and development, implementation and change, organization development, and policy. These are displayed in Figure 1, a modification of the one proposed by Guskey and Sparks (1996), mentioned earlier.

As Figure 1 illustrates, there are important relationships among quality professional development, various kinds of teacher learning, and student learning. The quality or nature of professional development consists of four clusters of variables: content (what is to be learned); process (how content is to be learned); strategies and structures (how content is organized for learning); and context (conditions under which content is learned).

Figure 1 also illustrates the multiple outcomes that professional development can produce, including teacher learning of new knowledge and teaching skills, changes in classroom practice, and leadership development; implementation of new curriculum or assessment programs; and changes in school and district culture. It illustrates the many factors outside of the teacher and student that have been found to influence teacher and student learning. The model is meant to illustrate that, when conditions in their school, district, and state context are supportive, if teachers make specific changes in their practice as a result of learning from professional development, then their students' learning can be improved.

In the following sections, we review research related to the components and relationships in the model. We begin by examining teacher learning, then the nature of professional development (i.e., the content, process, strategies and structures, and contexts) that contributes to that learning. We proceed to discuss

Figure 1. *Influences on the relationship between professional development and student learning.*



different elements of the system that influence professional development and teacher learning. We make special note of studies that also relate this complex of factors to student learning.

Teacher Learning and Expertise

The research on professional development rests on a sound body of knowledge regarding the importance and nature of teacher expertise and teacher learning. A recent report of the NCTAF (1996) reported two critical findings. First, teacher expertise is one of the most important factors in student learning, followed by the influence of small schools and class sizes. The report's conclusion: "Teachers who know a lot about teaching and learning and who work in environments that allow them to know students well are the critical elements of successful learning (Darling-Hammond, 1998, p. 6)." Second, teacher knowledge of subject matter, student learning and development, and teaching methods are all important elements of teacher effectiveness. The broad-based research cited in the report indicates that the conventional wisdom is wrong: anyone cannot teach, and teachers are not born. As the report concludes: Students profit from their teachers' opportunities to learn (Darling-Hammond, 1998).

Research on Teacher Learning

A recent report on the science of learning from the National Research Council (NRC, 1999), began with the assumption that principles of learning hold as true for teachers as they do for all learners. The "new principles of learning," summarized in the report, draw on new studies of the learning process and the development of competent performance. Some of the important themes that relate to how teachers learn included the following:

- To gain meaning and deep understanding, learners must build coherent structures of information organized around core concepts or big ideas of a discipline, rather than collect facts and principles through memorization. Thus teachers need a sound foundation in the major ideas of the disciplines they teach and a deep understanding of how students come to learn those disciplines.
- Studies of expert performance illustrate what successful learning looks like. Experts use problem solving techniques unique to their disciplines to access relevant pieces of their store of information. Thus teachers need to be skilled in how to make decisions about what students know, what they need to know, and how they can be helped to gain that knowledge—and the knowledge to help their students do so.
- In order to transfer learning, i.e., to ensure that learning has long-term influence over other kinds of learning and performance, learners need to understand major concepts and generalized principles, plus when and how to apply what they have learned. Thus teachers need to know what knowledge to apply in what learning and teaching situations.
- Learners are aided by self-monitoring and analysis of what they are learning and how. Thus teachers' learning is enhanced by the opportunities and the tools for self-assessment and the disposition to act on information they gather.
- Learning is influenced by participation in a community, by its norms, its constraints and resources, and its limits and possibilities. Thus teacher learning is enhanced by interactions that encourage them to articulate their views, challenge those of others, and come to better understandings as a community.

Research on Learning to Teach to New Standards

Recent research on mathematics teacher learning (Ball, 1996) focused on the challenge of helping teachers teach to new and higher standards, in particular, the standards of the National Council for Teachers of Mathematics (1989). Darling-Hammond and Ball (1998) summarized that research in the following five points:

1. Teachers' prior beliefs and experiences affect what they learn. As Cohen (1988) has pointed out, many teachers hold deep-seated conceptions of knowledge as facts, teaching as telling, and learning as memorizing. These beliefs are anathema to the new reforms and, only when they are dispelled, can teachers teach for understanding.

2. Learning to teach to the new standards takes time and is not easy. According to Darling-Hammond and Ball (1998), many teachers must face their deeply held beliefs about learning and knowledge and must reconsider their assumptions about students. Most teachers, even if their beliefs are consonant with the new reforms, must develop new ways of teaching and assessing their work. Fundamental change in practices and beliefs takes time, because there is much to unlearn and much that is complex to learn.

Further, research by Huberman (1993, 1995) indicated that the way teachers typically change is through what he calls "bricolage," or tinkering. Like independent artisans, teachers pick up new

techniques, activities, and materials that fit their own styles and adjust them based on their goals and experience. As Thompson and Zeuli (in press) noted, "This kind of craftsmanly tinkering is quite practical and eminently sensible, but it is also quite conservative ...[enabling] a teacher to preserve a style and set of fundamental ideas about subject matter, teaching and learning. . . (p. 14)." Helping teachers shift both what they learn and how they learn it adds to the complexity of the learning challenge.

3. Content knowledge is key to learning how to teach subject matter so that students understand it. Teachers cannot help students understand what they themselves do not understand. In addition, they must understand the content within the context of the experiences and cognitive abilities of their age students.

4. Knowledge of children, their ideas, and their ways of thinking is crucial to teaching for understanding. This is the focus of a great deal of current research in both mathematics and science. Researchers studying student mathematics learning have come to understand what concepts students can best learn and when (Ferrini-Mundy, 1997). In mathematics, many professional developers have based their programs on that research. Their own studies demonstrate the value of helping teachers understand how to listen to their students, how to help their students demonstrate their thinking, and how to interpret student work (Ball, 1996; Fennema et al., 1996; Schifter, 1996). Taking a somewhat different tack from the mathematics research, science education research has focused on the misconceptions of students about fundamental scientific concepts (Wandersee, Mintzes, & Novak, 1994) and subsequently explored the value of building that kind of knowledge into curriculum materials and professional development for science teachers (Bybee, 1997; Loucks-Horsley, 1996).

5. Opportunities for analysis and reflection are central to learning to teach. As noted previously in the discussion of principles of learning, all learners benefit from self-monitoring and reflection on their own learning and the application of new knowledge to their practice.

Quality Professional Development

The research on teacher learning forms a foundation for our exploration of studies illuminating the (a) content, (b) process, (c) strategies and structures, and (d) context of quality professional development.

The Content of Professional Development

Research on teacher learning has underscored the need for professional development to help teachers understand (a) subject matter, (b) learners and learning, and (c) teaching methods. Most studies indicate that professional development combining these content goals provides teachers with what they need to teach their subject matter well. In his studies of expert teaching, Shulman (1986) identified a special kind of teacher knowledge that is distinct in many ways from understanding of subject matter content, understanding of learning in general, and generic teaching skills or methods. He coined the term, "pedagogical content knowledge," for the knowledge and abilities possessed by the experienced, expert teacher that includes what concepts in a discipline are most appropriate for students of a certain age, how the students come to understand those concepts, what naive conceptions or misconceptions they are likely to have, and what representations, examples, and experiences help them learn. According to Shulman, pedagogical content knowledge is the province of experienced teachers; new teachers and teachers new to a subject or grade level need to acquire it through study and reflection on their teaching practice. This connects directly to the learning research summarized above, which emphasized understanding major concepts of teaching and learning of a particular subject matter, and knowing how to apply that knowledge to new and challenging situations.

In a recent review of in-service programs that demonstrate evidence of improved student learning, Kennedy (1998) determined that programs helping teachers learn how students learn the subject matter are most successful in improving student achievement. Kennedy explained that, by learning how students learn the subject matter, teachers also (a) learned the subject matter content themselves; (b) learned how to recognize if and how students are learning; and (c) learned ways to teach the specific subject matter. All three are aspects of "pedagogical content knowledge." One program in the Kennedy study that demonstrated improved student learning is Cognitively Guided Instruction, in which teachers learned a research-based model of children's thinking by constructing their own models in specific mathematics content areas (Carpenter, Fennema, & Franke, in press; Fennema et al., 1996).

Processes for Professional Development

As the research begins to illuminate the optimal content of professional development, so too are we learning about effective processes through which teachers learn. The NRC (1999) study cited above described four characteristics of environments that promote learning. Applied to our topic, effective learning experiences for teachers are

1. Learner-centered: Effective learning experiences acknowledge and bring into the activities what teachers know and are able to do, which serves as a foundation on which to build bridges to new understandings (Duckworth, 1987).

2. Knowledge-centered: Teachers need opportunities to develop well-organized bodies of knowledge of their disciplines that support planning and strategic thinking. Knowledge-centered environments take seriously the need to help teachers become knowledgeable by learning in ways that lead to understanding and subsequent transfer (Bruner, 1981). The "progressive formalization" process is currently being used to develop curricula for students and also to frame professional development for teachers (NRC, 1999). In this process, learning begins with the informal ideas and preconceptions of the learners. Through structured activities, they gradually learn to be metacognitive and to explore, explain, extend, and evaluate their progress. As learners build, transform, and formalize their ideas, they acquire the concepts and procedures of a discipline. Ultimately, they develop the kind of knowledge that characterizes expertise: they "learn their way around" a discipline and can make connections (maps) between objectives. In the case of teachers, their "discipline" is the learning and teaching of their particular subject matter.

3. Assessment-centered: Effective teacher learning opportunities provide opportunities for feedback and revision. They give teachers time to reflect and help them be more reflective about what they are learning and how they will apply what they learn.

4. Community-centered: Effective learning experiences for teachers build in time for teachers to work together and provide each other feedback. They have norms for people learning from one another and continually attempting to improve.

These four characteristics of effective learning environments provide a backdrop for the specific kinds of learning experiences teachers need to implement challenging reforms in science and mathematics. Concerned about the discrepancy between current teacher beliefs and practices and those required by the current reforms, Thompson and Zeuli (in press) discussed research studies that suggest several requirements for professional development. According to their review of research, professional development must

1. Create"a sufficiently high level of cognitive dissonance to disturb in some fundamental way the equilibrium between teachers' existing beliefs and practices on the one hand and their experience with subject matter, students' learning, and teaching on the other (Ball & Cohen, in press)" (p. 23).

2. Provide time, contexts, and support for teachers to think and work at resolving the dissonance through discussion, reading, writing, and other activities that amount, essentially, to the crystallization, externalization, criticism, and revision of their thinking.

3. Ensure that the dissonance-creating and dissonance-resolving activities are connected to the teachers' own students and context (Ball & Cohen, in press; Brown, Collins, & Duguid, 1989; Huberman, 1995).

4. Provide a way for teachers to develop a repertoire for practice that is consistent with the new understandings they are building (Huberman, 1995; Collins, Brown, & Newman, 1989).

5. Provide continuing help in the cycle of surfacing new issues and problems that will inevitably arise from actual classroom performance, deriving new understandings from them, translating these new understandings into performance, and recycling.

A 1996 synthesis of standards for professional development noted a great deal of consensus on the value of teacher learning experiences based on sound principles of learning that model how teachers are to teach their students. These principles include active engagement, learning over time, and opportunities to practice and apply what is learned to the teacher's own context (Loucks-Horsley, Stiles, & Hewson, 1996).

Surveys of professional development indicated large discrepancies between what is known to be effective and what teachers experience as professional development (Loucks-Horsley, Hewson, Love, & Stiles, 1998; NCTAF, 1996). Often professional development occurs in one-time sessions in which teachers do not have the opportunity to study in depth new ways of learning and teaching their subject matter. Their learning is not focused on their subject matter, connected to their own teaching, nor do they have opportunities to build relationships with their colleagues by studying closely together. Further, professional development is disconnected from other initiatives in the school or district — ones that touch the very same teachers but are experienced by the teachers as having different goals, activities, and organizational arrangements.

Efforts to design professional development that departs from this scenario and incorporates some of the characteristics of effective professional development described above are becoming more common. Darling-Hammond and Ball (1998) noted several lines of work that have this potential:

- Developing professional discourse around problems of practice. Traditional forms of professional development provide answers to

questions. They convey information, teach skills, provide curriculum materials with practice in how to use them. More powerful professional development is based more closely on the principles of active learning, shortcutting the distance between new knowledge or skill learned and applications to the classroom. Using an inquiry orientation rather than one of finding answers or solutions, these experiences use artifacts of practice such as student work, teacher journals, classroom videos, or narrative cases (Ball & Cohen, in press). As they examine and analyze these materials, their discourse delves deeply into important issues around learning and teaching.

- Content-based professional development. Traditionally, coursework in one's teaching discipline and professional development in generic teaching skills, such as designing instruction and cooperative learning, were separate. With the backdrop of research on expert learning and on pedagogical content knowledge, researchers have begun to look at teachers' opportunities to develop content understanding that will be useful in their teaching — which is often neither the topics selected nor the treatment given by typical university science and mathematics courses.

Strategies and Structures for Professional Development

Traditionally, professional development has been in the format of in-service workshops, largely of short duration, and college coursework. In the past decade, a variety of new formats have been developed that take into account the principles of professional learning described in the previous section, such as connections to teachers' own work with their students; links to subject matter and concrete tasks of teaching; and sustained over time by ongoing conversations and in-class coaching (Little, 1993).

Loucks-Horsley et al. (1998) identified 15 different strategies that are used for professional development for teachers of science and mathematics, which fall roughly into five categories (see appendix).

Immersion. Immersion strategies involve participants in "doing" science and mathematics. Science teachers inquire into natural phenomena; mathematics teachers solve mathematical problems. Included in this category are programs in which teachers work in their content field for extended periods of time, e.g., spending a summer on a research team in a laboratory or industrial setting, and programs in which teachers work on mathematical problems or conduct scientific inquiries to learn how to and gain the experience of doing so.

Curriculum. Curriculum strategies involve teachers with the actual learning experiences and materials they will use with their students. Teachers learn how to implement new curriculum materials, adapt or develop their own curriculum materials, or teach a unit on a topic that is new to them or is taught in a new way — all of which can build in teachers new content knowledge, teaching skills, and dispositions towards other ways of teaching.

Examining practice. Professional development strategies focused on teachers' own practice afford direct "job-embedded" learning. Several different "artifacts of practice" (described in the previous section) can be the focus of this kind of learning: students' work, their responses to assessments, and their thinking, as carefully observed and documented by their teachers; video or narrative cases of teaching dilemmas or situations; or data collected by teachers conducting action research on questions of their choosing about their students' learning.

Collaborative work. Collaborative strategies for professional learning include professional networks inside schools and across school boundaries, partnerships with scientists and mathematicians, and coaching and mentoring. These afford teachers important opportunities to share "craft wisdom" and build a professional culture that focuses collective energy on student learning.

Vehicles and mechanisms. These strategies are actually structures through which learning of various kinds can occur. Workshops and institutes are by far the most common structure through which teachers have opportunities to learn; although they are overused, they can be powerful when selected for the correct purpose and designed well. Technology is increasing in its use for professional learning and, like other strategies, can be effective if designed with principles of effective professional development in mind. Developing professional developers is a strategy that prepares teachers and other educators to provide professional learning opportunities to others.

In their attention to design of professional development programs and initiatives, Loucks-Horsley et al. (1998) indicated that strategies are typically used in combination. Several strategies may be part of the same intervention, e.g., a workshop in which teachers learn to implement new curriculum materials, followed by regular coaching in their classrooms. Or several strategies may be used in sequence, e.g., use of curriculum replacement units followed by case discussions and action research focused on the use of the units.

Although not all of the strategies have been the focus of careful research, many have been. For example, research indicates that the use of case discussions can be a powerful strategy for learning, particularly for mathematics teachers. Studies of the use of case discussions by Barnett (1998) and teacher narratives by Schifter (1996) have indicated gains in teachers' knowledge of mathematics content, their understanding of students' thinking in mathematics, and their orientation, skills, and changes in teaching mathematics.

Curriculum implementation is another strategy gaining wide use because of the necessity for reform-oriented science and mathematics teachers to have materials focusing on outcomes from the national standards and promote inquiry-based learning (National Science Foundation, 1997). This is especially true in the elementary schools where teachers have limited content knowledge; professional development focused on the use of new materials appears to result in teacher gains in content knowledge and in motivation to deepen that knowledge even more. Cohen and Hill (1998) and Russell (1998) examined the strategy of professional development in which teachers studied the curriculum they used with their students and found gains in teacher understanding of content but, in the case of the Cohen and Hill study, in student learning as well. Research on coaching (Showers & Joyce, 1996) and on professional networks (McLaughlin, 1993; Webb, Tate, & Heck, 1995) has illuminated the nature and value of teacher-to-teacher feedback, support, and codevelopment of curriculum as contributors to professional learning.

Contexts for Professional Development

Research on the influence of context on teacher and student learning has come from a variety of perspectives, among them educational anthropology and sociology, organization development, educational change and school improvement, and systems thinking. The importance of a supportive context to science and mathematics professional development became clear in the 1960s and 1970s, when teachers who attended exciting NSF-funded institutes found it difficult to apply their learning once they returned to their schools. There, they often lacked administrative, collegial, material, and parental support required to use the new curricula and practices they had learned.

Many studies of the importance of context to professional development have not focused on science and mathematics teachers, but on teacher learning in general. In 1982, Little found that norms of collegiality, collaboration, and experimentation characterized schools in which teachers learned continuously. Rosenholtz (1991) discovered distinct differences in what she termed "learning-enriched" and "learning-impoverished" schools; in "learning-enriched" schools teachers interacted frequently and worked closely together around issues of teaching and learning. Research on the QUASAR project, which developed reform-oriented mathematics programs in urban middle schools, described a school in which a strong professional practice community nurtured teacher learning and collaboration and was particularly effective in inducting new teachers into a culture focused on effective teaching and learning (Stein, Silver, & Smith, 1998). In all three studies, increased student achievement accompanied the collaborative cultures.

As demands for accountability increase, researchers and evaluators are paying close attention to the particular characteristics of school and district professional development initiatives that foster improved student learning. This is especially true because collaboration per se does not appear to guarantee improved achievement; studies by Fullan and Hargreaves (1996) and McLaughlin (1993) have found collaborative environments that stifle innovation and reinforce traditional practice. Often it is the focus of the collaboration that leads to learning gains.

For example, in schools recognized by the U.S. Department of Education for having model professional development programs, professional development decisions were directly aligned with student learning goals. Through elaborate processes, staff of these schools worked collaboratively to analyze student achievement data and determine goals for teacher knowledge and skill and long-term school improvement plans (Killion, 1998b).

Similarly, the Self-Renewing Schools Study found the successful programs were ones in which school staff identified professional development needs on an ongoing basis through close monitoring of student learning (Joyce, Wolf, & Calhoun, 1993). The Success for All program from the Center for Research on Effective Schooling for Disadvantaged Students at Johns Hopkins University is one of the programs that this study identified as successful in improving student achievement.

Success for All is a complex initiative that combines an intensive reading (and mathematics) curriculum with close-order diagnosis of learning problems, immediate intervention with tutoring aimed directly at the problems, cooperative learning, and family support teams. The staff development program is spread throughout the year, with heavy emphasis on follow-up implementation (Joyce et al., 1993). Through professional development, teachers and family support teams learn to combine curriculum, instruction, and

tutoring to meet individual students' learning needs.

Two more examples of "self-renewing" schools are the Schenley High School in Pittsburgh, Pennsylvania, and Richmond County, Georgia. The dramatic successes in student achievement in nine curriculum areas at the Schenley High School, can be attributed to its collaborative learning environment. Concentrating the "most highly regarded" teachers in one school resulted in a "jacked up" learning environment that intensified focus on instruction and in immediate, large, and sustained rises in student achievement on standardized tests.

In Richmond County, Georgia, schools joined the School Improvement Program if 80% of the faculty voted to participate. School faculties were organized into study groups and participated in professional development focused on "models of teaching selected to increase the learning capacity of their students [with resulting increase in student learning due to a] combination of teacher knowledge and changes in practice and the increases of energy, positive social climate, and collegiality of the faculty" (Joyce et al., 1993, pp. 70-71).

The effective large-scale improvement initiatives identified by Joyce et al. all focus on specific student-learning goals. They used procedures (including professional development) tailored to these goals and backed by rationales grounded in theory or research or a combination. The initiatives measured learning outcomes on both a formative and summative basis, not leaving evaluation to a yearly examination of post hoc information derived only from standardized tests, They recognized the need to provide robust, content-focused professional development

Research on successful schools with high student achievement also highlights the need for strong leadership for professional development. In their study of low and high performing schools, the Georgia Council for School Performance (Harkreader & Weathersby, 1998) found higher performing schools to have principals, central office staff, and other decision makers who were advocates for professional development focusing on student achievement, school goals, and staff's needs. These leaders sought resources for staff development and motivated staff to participate (Killion, 1998a).

Strong leadership is one of several factors contributing to remarkable student achievement gains of New York Community School District #2, the focus of a series of studies by the Learning Research and Development Center at the University of Pittsburgh. District #2's attention to principals as the key actors in instructional improvement emerged as one of the "general principles in their theory of action" (Elmore & Burney, 1997). Elmore and Burney reported that, unlike those in other districts, District #2 principals all articulated the same expectations and values for instructional improvement for high student performance.

District #2 is also a rich example of the development of "nested" learning communities at every level—classroom, school, and district:

> The concept of nested learning communities... embraces all educators as working professionals. It envisages teachers, principals, and senior administrators as learners — becoming increasingly expert as conductors of learning communities in the classroom, the school, and the district — by functioning regularly as members of a community of adult learners focused on improving their practice as educators. It established schools as places where learning is the work of both students and professional educators, and where continuous learning and improvement are the norm. (High Performance Learning Communities Project, 1998, pp. 2-3)

District #2's success of "high performance learning communities" depended on clearly defined standards for what constitutes good teaching practice (with expectations that they be met by every teacher) and district goals and standards that are public, modeled whenever possible, and discussed. In these learning communities, teacher isolation was broken down by opening classroom doors. Teachers worked together on a number of instructionally related tasks and received encouragement and rewards for participation in professional development.

Five themes emerging from the District #2 research provide insight into strategies that can move an entire district of diverse schools toward improved student achievement through professional development (Elmore & Burney, 1997):

1. The phased introduction of instructional changes organized around content areas. The district spent several years on literacy, then recently introduced mathematics as a target for improvement. This strategy focused efforts and facilitated demonstration of accountability.

2. The intentional blurring of the boundaries between management of the system and the activities of staff development. This theme was captured by the quote, "Management is professional development," which means principals are responsible for professional development. Principals oversaw use of the district's Professional Development Laboratory, outside consulting services, intervisitations and peer networks, and off-site training.

3. A complex and evolving balance between central authority and school-site authority. A shared belief across the district in professional development as the key to instructional improvement allowed schools to initiate their own plans and budgets toward the district's priorities on particular content areas.

4. Unapologetic exercise of control in areas central to the success of the decentralized strategy, most notably the recruitment, selection, training, and retention of staff. With instructional improvement as the focus, principals and teachers were hired and trained on the basis of their success toward this goal.

5. Consistency of focus over time. Instructional priorities were defined and held over long periods to avoid "fads of the moment." Consulting, management, and oversight processes helped educate principals and teachers in their central role in instructional improvement.

District #2 is an example of a system in which professional development has played a key role in improvement. Context factors (such as clear standards for students and teachers, strong leadership, and collaborative work) focused teacher learning on student learning. In the current science and mathematics reforms, initiatives to change district and state systems have focused large amounts of resources on professional development while aligning policies and practices for curriculum, teaching, and assessment as well.

Organizational context extends to systems as well — school systems, state systems, national systems. The recent movement toward systemic reform acknowledged the importance of elements of the system changing in order to change and then sustain changes in individual teachers and classrooms — in short, to reform the education of young people. The role of professional development has always been seen as a critical element in the success of systemic reform (Smith & O'Day, 1991).

Research studies reiterated the need for system elements to change in alignment with what teachers are learning to do: when assessments, certification requirements, and reward systems support new behaviors on the part of teachers, their learning takes on new meaning within a common set of goals and challenges (Cohen & Hill, 1998; Corcoran, Shields, & Zucker, 1998). In its evaluation of the 24 National Science Foundation-funded Statewide Systemic Initiatives (SSIs), Stanford Research International (SRI) reported that SSIs' professional development was of high quality and effective with the educators they trained (Corcoran et al., 1998). In several states whose interventions focused largely on professional development, student gains in science and mathematics achievement were found (Kahle, 1999; Radford, 1998). However, the SRI study found that the impact of the SSI professional development initiatives was severely limited by state and district policies, costs, and scale issues. The study found that SSIs were hampered by lack of alignment of state policies for professional development; they were caught in a balancing act of work that had a limited and local focus while they were trying to implement large-scale changes. Researchers postulated that the impact of state-initiated professional development implemented locally could be significant if a state has a strong accountability system to measure student achievement (Corcoran et al., 1998; Laguarda, 1997).

State and district reform initiatives are beginning to illuminate the particulars of effective large-scale professional development. In research conducted on mathematics professional development in California, Cohen and Hill (1998) explored the relationship among state policy, teacher learning, and student achievement. They examined the influence of assessment, curriculum, and professional development on student achievement as a function of implementing state mathematics reform policy. Their results suggest a model in which teacher knowledge, teaching, and assessment practice is influenced when policy provides opportunity for teacher professional development — in particular, professional development focused on the teachers' own curriculum was related to improved student performance.

Professional development for science and mathematics teachers has also been the focus of systemic initiatives at the district level. Local systemic initiatives in large districts and collections of districts that use new NSF-funded curricula and include all teachers (not just volunteers) have shown widespread change in science and mathematics teaching (Weiss, Montgomery, Ridgway, & Bond, 1998). There is also some evidence of improvements in student learning: This has been the case in the Merck Institute's collaboration with four districts in New Jersey focused on reform of K-8 science programs (Consortium for Policy Research in Education [CPRE], 1998) and in Project IMPACT, a Montgomery County, Maryland, project focused on middle grades mathematics (Campbell & Robles, 1997).

Putting it All Together

This article has discussed the research on the content, processes, strategies and structures, and contexts in which professional development is effective

and, in some cases, is able to demonstrate a link to improved student learning. The characteristics of effective professional development framed by these four areas, however, cannot simply be applied to every teacher learning situation in the same way. A study of the practices of experienced professional developers conducted by the National Institute for Science Education (NISE) found that each situation that calls for teacher learning requires a unique design that combines elements of effective professional development in different ways (Loucks-Horsley et al., 1998).

The NISE study proposed a framework for professional development design: a process through which professional developers assess their context, set goals, and create a program that draws on the research discussed in this article, selects and combines various strategies from those described earlier, and results in a design for professional learning tailored to the unique situation in which teachers work. This emphasis on design responds to the complexity of professional development and the unlikelihood that research will result in a formula that applies to every setting. As this article indicates, however, research has identified many elements of and conditions in a system that are likely to influence the success of a professional development program. Although much of the research has not attempted to tie professional development directly to student learning outcomes, there are increasing numbers of studies that do so. Those that do point to the importance of:

- Curriculum-based professional development (Cohen & Hill, 1998; CPRE, 1998).
- Focusing professional development on student thinking (Fennema et al., 1996; Kennedy, 1998).
- Goal-focused, collaborative, supportive school and district environments (Elmore & Burney, 1997; Joyce et al., 1993; Little, 1982; Rosenholtz, 1991).
- Paying attention to and aligning other elements in the system, e.g., assessment, curriculum, administrative support (Cohen & Hill, 1998; CPRE, 1998; Kahle, 1999).

Interestingly enough, the findings of studies that examine student learning are similar to those that do not, suggesting an emerging consensus. The challenge ahead is to deepen the knowledge base and make it accessible to practicing professional developers to inform their critical decisions about professional development design.

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Appendix
Professional Development Strategies (from Loucks-Horsley et al., 1998)

Immersion
- Immersion into Inquiry and Problem-Solving
- Immersion into the World of Science and Mathematics

Curriculum
- Curriculum Implementation
- Curriculum Replacement Units
- Curriculum Development/Adaptation

Examining Practice
- Action Research
- Case Discussions
- Examining Student Work and Thinking, and Scoring Assessments

Collaborative Work
- Study Groups
- Coaching and Mentoring
- Partnerships
- Professional Networks

Vehicles/mechanisms
- Workshops, Institutes, Courses, Seminars
- Technology for Professional Learning
- Developing Professional Developers

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Now after 13 years as editors of the Problems Section, Dick and Laszlo are retiring. Throughout their editorship, they have provided a tremendous service to the profession. Their work has stressed the vision of the NCTM standards long before the standards existed.

The editorial staff of the School Science and Mathematics journal has particularly appreciated working with both Dick and László. Their commitment to quality and timeliness in the Problems Section has constantly been evident in their work. On behalf of the membership of the School Science and Mathematics Association, we would like to sincerely thank them for the wonderful job they have done over the years. We know they will continue to give to the profession, and the profession will be better because of their contributions.

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