STAR Science Assessment professional development (www.maincenter.org/star.html).

Strengthening Science Inquiry Assessment and Teaching Project. WestEd (www.wested.org).

WestEd and the WGBH Educational Foundation. (2003). *Teachers as learners: A multimedia kit for professional development in science and mathematics*. Thousand Oaks, CA: Corwin Press. (See Tape 3, Program 3, *Assessing student work, Arizona State University East, Mesa, AZ*, and Tape 4, Program 5, *Examining content and student thinking, Urban Calculus Initiative, TERC, Cambridge, MA*.)

Lesson Study

Katie, Aiden, and Leah, three third-grade teachers, wanted to start lesson study as a professional learning strategy in their school. They, and almost all of the other teachers and the principal, were already conducting cross-grade and content-alike study groups, had an effective mentoring program in place for new and experienced teachers, and spent numerous hours weekly examining their students' work and thinking to better meet the learning needs of all students. Given the diversity of learning experiences at the school and the collegial culture in place, they believed they were ready—as individuals and a faculty—to embark on lesson study.

They started by first learning more about lesson study by reading The Teaching Gap *and better understanding the contextual issues that influenced the success of lesson study in Japan. They also read numerous articles and studies done by researchers at Teachers College at Columbia University and visited a myriad of Web sites on lesson study. By the end of the semester, they felt ready to try lesson study.*

Katie took the lead on compiling the data they had from their classrooms and from the state test in mathematics to help them identify specific learning goals that needed to be addressed. After they analyzed the data and saw patterns in their students' ability to reason and problem solve, they decided to focus their first lesson on improving their students' abilities in these areas. Throughout the year, and into the next year, Katie, Aiden, and Leah studied the NCTM standards and TIMSS mathematics videos and developed a lesson aimed at increasing students' ability to use proportional reasoning. They followed the eight-step structural design for lesson study as outlined in The Teaching Gap, *including defining the problem, planning the lesson, teaching the lesson, evaluating the lesson and reflecting on its effect, revising the lesson, teaching the revised lesson, evaluating and reflecting again, and sharing the results. They identified a terrific mathematics educator from the state college nearby who provided feedback and helped them think through why some parts of the lesson were not effective. During the next two years, additional teachers joined Katie, Aiden, and Leah and a group of four teachers decided to begin focusing their lesson study experiences on science lessons.*

The Third International Mathematics and Science Study (TIMSS) has shed light on the extent to which education in the United States supports the learning of all students, provides teachers with opportunities for professional learning, and translates national standards into policy and practice. Since TIMSS data were released, discussions have continued concerning ways in which to improve the U.S. educational system. Given the contrasts between the TIMSS results from the United States and Japan, many educators in the United States have analyzed and discussed what can be learned from the Japanese education system to improve education in our own country. Japanese lesson study is a professional learning strategy that has received much of the attention.

In Japan, lesson study is a structured process through which teachers' develop lessons to enhance student learning in all subject areas. Use of lesson study results in teachers developing a thorough understanding of how a particular lesson should be conducted and why. Groups of teachers meet regularly over long periods of time (e.g., several months to several years) to work on the design, implementation, testing, and improvement of one or several lessons (Stigler & Hiebert, 1999). Research lessons are at the core of lesson study—groups of teachers discussing, teaching, observing, and revising specific lessons that are designed to enhance student learning of specific concepts and content. Lesson study and the accompanying research lessons are supported and advocated by all educators and seen as an inherent part of being a teacher. As one Japanese teacher noted, "Why do we do research lessons? I don't think there are any laws [requiring it]. But if we didn't do research lessons, we wouldn't be teachers" (Lewis, 2002b, p. 60). Increasingly, educators in the United States are exploring ways in which to transfer lesson study as a strategy for professional development, especially in science and mathematics, into schools in the United States.

Key Elements

Teachers collaborate on the development and refinement of lessons. In lesson study, teachers collaborate with each other in every aspect of the teaching process, from planning lessons to assessing student outcomes. Engaging in lesson study requires that teachers voluntarily participate with a motivation to learn from each other

KEY ELEMENTS FOR LESSON STUDY

- **Teachers collaborate on the development and refinement of lessons.**
- **The results of lesson study benefit all teachers and students.**
- **The focus of the lesson studied and researched is directly related to standards and school goals.**
- **Critical feedback is on the effectiveness of the lesson and not the teachers' performance while teaching.**
- **Enhancing teacher and student learning is grounded in practice.**
- **There is a structured process for guiding the lesson study.**

toward the goal of improving student learning. Inherent in the process of researching a lesson is the belief that discussing others' points of view enhances the learning process and the final product, the lesson itself. In addition, teachers' reflection on their own teaching practices and their students' learning comprises a major emphasis of the lesson study process. Engaging in lesson study presumes that participating teachers have the desire to enhance their own learning and their students' learning through interactions with their colleagues and self-reflection.

The results of lesson study benefit all teachers and students. Not only does engagement in researching lessons result in the individual learning and growth of teachers, but also the product developed enhances the learning of students in participating teachers' classrooms. The concrete product of lesson study is well-researched, conceptually grounded lessons that promote students' learning of science or mathematics concepts. The participating teachers incorporate the lessons into their overall curriculum and, often, the new lessons are shared with teachers at other schools. In this way, the benefits extend to numerous teachers and students. Teachers who have engaged in lesson study also relate that they transfer the skills and knowledge that they learn during the study of specific lessons into other content areas.

The focus of the lesson studied and researched is directly related to standards and school goals. To benefit students and teachers beyond those directly involved in the lesson study experience, the themes or concepts being addressed in the lessons must be a reflection of school, district, or national standards and goals for student learning in science or mathematics. In addition, identifying the concepts to explore through lesson study should be based on data that indicate there is a need for improvement in current student achievement or learning.

Critical feedback is on the effectiveness of the lesson and not the teachers' performance while teaching. Although this is a subtle distinction, it is a critical one. The focus of lesson study is on the lessons and the ways in which the teaching and learning strategies enhance student learning. The individual teacher conducting the lessons, who is observed by the other teachers, is not at the center of improvement. Individual teachers do, however, often relate that they gain immense knowledge about ways in which to improve their teaching through reflecting on the feedback from their peers. Keeping the critical feedback discussions focused on the lessons and the student learning that results enhances teachers' comfort level with engaging in a discussion of the strengths and weaknesses of the collaboratively designed lessons.

Enhancing teacher and student learning is grounded in practice. Lesson study is not a professional development strategy that occurs devoid of context. It is firmly grounded in the work of teachers and students. As noted in other strategy descriptions, research continues to emerge that demonstrates that when professional development is directly connected to what teachers teach and what students learn, teachers' understanding and implementation of best practice increase (e.g., Cohen & Hill, 1998).

There is a structured process for guiding the lesson study. Numerous resources have been published describing varied approaches to conducting lesson study, both as it occurs within schools in Japan and how it has been adapted to meet the cultural and contextual issues within schools in the United States (see the Resources section). Most researchers and educators, however, outline a similar process (Lewis, 2002a; Stigler & Hiebert, 1999), which includes the following:

- Defining the theme or concept to guide the lesson study: The theme, topic, or concept to be studied should be based on data indicating a need to improve student learning as determined by local, state, or national standards and goals.
- Designing the lesson: Teachers research the topic or concept of the study, including examining what the research says about how students learn the concept and what common misconceptions students hold, and then collaborate to develop a lesson plan, which is then shared with a larger group of teachers for additional feedback and revision. Although individual lessons are developed and studied, several lessons relating to the defined concept or goal are designed and studied over time.
- Teaching the lesson: One teacher teaches the lesson, although all teachers participate in the preparation of the lesson and, sometimes, teachers role-play the lesson prior to teaching it in the classroom with students.
- Observing the lesson: While the lesson is being taught, the other teachers observe and take notes on what the students and presenting teacher do and say, following the "storyline" of the lesson, and document the questions the presenting teacher asks and the student responses.
- Reflecting and evaluating: Critical, in-depth discussions focus on what was observed during the teaching of the lesson.
- Revising the lesson: Based on their reflections and evaluation, the lesson is collaboratively revised and, frequently, examining student work is used to guide decisions regarding how to enhance the lesson to increase student understanding and learning.

- Teaching the revised lesson: The revised lesson is taught and observed; the same teacher may teach the lesson again, to either the same or a different group of students, or another teacher may conduct the lesson, and, often, additional faculty members are invited to observe when the revised lesson is taught.
- Reflecting and evaluating: This second debriefing is attended not only by the lesson study teachers but also by a larger group of the faculty, the principal, and a "knowledgeable other"—a content expert, university faculty, or other outside professional. As Stigler and Hiebert (1999) note, the discussions in this second debriefing often extend to larger issues: "Not only is the lesson discussed with respect to what these students learned and understood, but also with respect to more general issues raised by the hypothesis that guided the design of the research lesson. What about teaching and learning, more generally, was learned from the lesson and its implementation?" (p. 115).
- Sharing the results: The lesson that has been researched and developed is shared with a broader audience of teachers and other educators. Articles might be published, and many schools and districts have established Web sites to share lessons that result from the process.

Implementation Requirements

Administrator support. As is evident from the procedure outlined above, lesson study can involve all teachers in the school, as well as teachers from other schools and knowledgeable others, and building supervisors must support the intense process of lesson study and structure the school day in ways that provide opportunities for teachers to plan, design, teach, and reflect together.

Access to resources and knowledgeable others. Lesson study teachers need readily available access to the resources required to study and research the theme or concept that they are exploring through the research lesson and have appropriate resource people who can serve in the "knowledgeable other" role.

Examples

Since 2000, Paterson Public School 2, a kindergarten through eighth grade school in New Jersey, has been using lesson study as a schoolwide strategy for professional development. The school started using lesson study as a means of improving teaching and learning in 1997 after a TIMSS

seminar motivated teachers to change the way they taught mathematics. With strong support and involvement of the school's principal, schedules were rearranged and teachers began study of student learning through lesson study. They did not, however, embark on their efforts without guidance. They collaborated with educators from Columbia University, the principal and teachers from the Greenwich Japanese School, and the Mid-Atlantic Eisenhower Regional Consortium for Mathematics and Science Education. With structures in place, a culture in the school supporting reflective risk taking and partners, mentors, and coaches ready to collaborate, some of the Paterson teachers initiated lesson study in mathematics. By the end of 2002, "all mathematics teachers (with the exception of one who opted not to participate) are scheduled from 80–105 minutes per week for lesson study" (Liptak, 2002). A few science and special education teachers are also involved and a schoolwide focus on science lesson study will begin in 2003.

One of the unique aspects of Paterson's implementation of lesson study is their collaboration with the principal and teachers from the Greenwich Japanese School. These teachers were experienced in using lesson study and served as close mentors and coaches during Paterson's first year of exploring lesson study in their own school. Greenwich teachers facilitated the process of identifying a specific area of need in mathematics, designing and writing the research lessons, observing lessons, and modeling the focused critique following observations of the lesson being taught.

Paterson School now has lesson plans and curriculum in mathematics for two grade levels. It is, however, already documenting improvements in students' performance on state mathematics tests and is learning that there has been an increase in the number of students who go on to high school in their enrollment in Honors Algebra and Algebra II (Hoff, 2000).

Another district, Bellevue School District in Washington, uses lesson study to enhance and refine the district's overall curriculum. Because it is an "instituted" professional learning strategy, several organizational and support strategies were put in place by the district's superintendent. Since 2000, all students in the district are released early once a week to provide time for teachers to meet and examine lessons. Lesson study leaders receive stipends and their own professional development and training. Teachers have time during the academic day to observe in each other's classrooms, and principals actively support and are involved in all aspects of designing, observing, and discussing the lessons. Lessons are then posted on the district Web site for all teachers to use in their classrooms.

Because it is a districtwide process based on district curriculum, teachers in separate schools can benefit from the lessons developed in another school. Common curriculum that all teachers teach is one of the critical elements that results in the success of lesson study in Japan and one that has posed challenges in the United States (see the Commentary section below). As Bellevue Superintendent Mike Riley stated, "It's not so much

reinventing the wheel, it's more like here's a picture of a wheel, now create one that will actually fit your car" ("A Superintendent's View," 2001).

Although lesson study is implemented throughout the Bellevue district, its use still requires in-depth shifts in the cultures in individual schools. The schools in Bellevue vary in the extent to which they engage in lesson study and those that are most actively involved describe schoolwide efforts to create more collegial environments. For example, the principal of an elementary school in Bellevue reflected on her school's implementation: "My school was ripe for lesson study. I had already spent a lot of time getting the staff together. We were in the habit of talking collaboratively about teaching and learning objectives. Now when we meet as a lesson study team, people feel free to suggest ideas. It's a safe place. It helps to have that teamwork in place. For a school that is less cohesive, lesson study could be the thing you use to bring people together" (Boss, 2001).

Commentary

It is tempting to jump on the bandwagon and import a strategy that clearly works so effectively in one setting into another setting. Several issues arise, however, when schools consider using lesson study as a strategy for professional development. First, as noted previously, the contextual and cultural environments differ vastly between Japanese and American schools as well as within American schools. For example, in Japan there is a national Course of Study that determines the content to be taught at each grade level and the curriculum addresses a few conceptual topics each year. In the United States, there are local, state, and national standards in science and mathematics and the curriculum addresses numerous topics each year. In fact, TIMSS revealed that for eighth-grade mathematics, the Japanese curriculum focuses on only eight topics while U.S. curriculum includes more than 65 topics (Schmidt et al., 2001). This difference between the two countries has implications for how teachers spend their valuable time. In Japan, they do not need to examine standards, translate those standards into curriculum, or select instructional materials to address the different concepts included in the curriculum. Rather, they can focus on enhancing the individual lessons they teach in their classrooms, with lesson study being the strategy to guide their planning and designing. In the United States, on the other hand, teachers often do not have the opportunity or time to focus on the lessons they teach; they are often overwhelmed by testing schedules, an overexhaustive curriculum, and limited opportunities within the school day to focus on their own teaching and learning.

Second, the culture of learning and the perceptions of the roles of teachers vary dramatically between the two countries. In the United States, there is also the issue of vast differences between the culture of learning in individual schools and districts. Lesson study requires a collaborative, critical examination of teaching and learning, and schools need to

determine whether such a community exists before attempting a lesson study approach.

Lesson study is much more involved than simply organizing and conducting demonstration lessons with observation. The eight-step process of lesson study distinguishes it from this, and it requires real collaboration among teachers and ideally with external resources—people and research—to expand views. Furthermore, lesson study must be an ongoing process and should be approached this way as one considers it as part of the professional development design for a school district. It involves more than the study of just one lesson.

Lesson study can be a catalyst for schoolwide reflection on the goals and vision for developing a more collegial faculty and encourage teachers and administrators to take steps toward achieving those goals.

U.S. educators and policymakers often turn to the quick fixes to solve the educational system's complex problems. Lesson study is based on the assumption that learning and change are gradual and intensive endeavors. As Stigler and Hiebert (1999) state, "Lesson study is a process of improvement that is expected to produce small, incremental improvements in teaching over long periods of time" (p. 121). Teachers and schools must necessarily consider the political climate that most directly influences their school and the parental and community perceptions of what reforming and changing teaching should entail. If the beliefs inherent in lesson study conflict with those critical factors, it is important to address them prior to implementing lesson study.

Finally, there is the overarching issue of how professional development is viewed. Although there have been significant shifts in recent years in the view of professional development as one-shot, short-term experiences disconnected from student learning, many educators still do not conceive of professional learning experiences, such as those described in this book, as effective strategies. Strategies like lesson study require a paradigm shift in thinking about what best-practice professional development looks like and is an issue that should be addressed prior to implementing a long-term, job-embedded learning experience for teachers.

Catherine Lewis has written extensively about lesson study in Japan and the United States. She raises several additional questions regarding the transfer of lesson study into schools in the United States, including the following:

- What are the essential features of lesson study that must be honored when lesson study is conducted in the United States (and what are the nonessential features that can be changed)?
- How do educators improve instruction through lesson study?
- What supports will be needed for lesson study in the United States, given its educational system and culture? (Lewis, 2002a, pp. 6-7).

Continued research and experience with implementing lesson study in this country will greatly enhance the education community's ability to answer the questions Lewis raises and increase the effectiveness of this strategy in the United States. As illustrated in the two examples above, there are schools that have successfully adapted lesson study to meet their specific school cultures and contexts. It is crucial to consider the specific contexts within a school before moving forward toward implementing lesson study. For example, teachers and administrators need to ask themselves: Does our learning culture support collaborative learning? How will we restructure time constraints to provide the necessary learning opportunities for teachers? Will the parents and community support this long-term, gradual approach to improving science and mathematics teaching and learning? Reflecting on these and other questions can guide a school or district to determine whether and when lesson study is the best strategy for teacher learning in their site.

Resources

Lesson Study Research Group, Columbia University (www.tc.edu/lessonstudy).

Lewis, C. (in press). *Lesson study: A handbook of teacher-led instructional improvement.* Philadelphia: Research for Better Schools.

Lewis, C., & Tsuchida, I. (1997). Planned educational change in Japan: The shift to student-centered elementary science. *Journal of Educational Policy, 12*(5), 313-331.

Northwest Regional Education Laboratory (www.nwrel.org/msec/nwteacher).

Paterson, New Jersey School 2 (www.paterson.k12.nj.us/~school2).

Stigler, J. W., & Hiebert, J. (1999). *The teaching gap: Best ideas from the world's teachers for improving education in the classroom.* New York: Free Press.

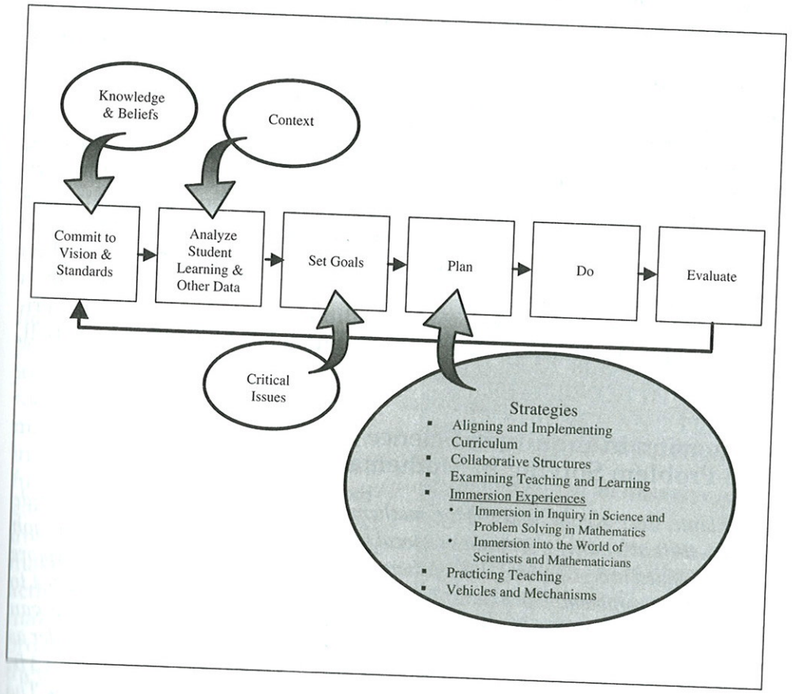
Yashida, M., & Fernandez, C. CD on lesson study. Available through Columbia University's Web site (www.tc.columbia.edu).

IMMERSION EXPERIENCES

The two professional learning strategies described in this section reflect approaches to teacher learning that engage teachers in doing science and mathematics: immersion in inquiry in science and problem solving in mathematics, and immersion in the world of scientists and mathematicians. (See Figure 5.5.) Both strategies are grounded in adult learning research indicating that learning is enhanced through direct experience of science and mathematics content and the processes of inquiry and problem solving.

Immersion experiences for teachers of science and mathematics are based on several assumptions about the disciplines of science and mathematics, teachers, learning, and professional development. These assumptions form the foundation for the design and implementation of all science and mathematics immersion experiences.

Figure 5.5. Strategies for Professional Learning: Immersion Experiences



Underlying Assumptions

Science and mathematics comprise process and content. The content of science and mathematics is the understandings, meanings, and models that have been created and continue to be created by scientists and mathematicians. Science and mathematics as inquiry and problem solving encompass the methodologies used to develop scientific and mathematics knowledge and understanding.

Teachers benefit from experiences as learners that are based on the same principles that they are expected to implement with students. As discussed in Chapter 2, the principles of human learning apply equally well to adults and children; they both learn through direct experience and by constructing their own meanings from those experiences using previous knowledge. Immersion experiences provide opportunities for teachers to learn science and mathematics content and processes at their own level of learning.

Teachers must have an in-depth understanding of science and mathematics content and processes. By becoming a scientist or mathematician through immersion in scientific inquiry or mathematical problem solving, teachers necessarily learn both content and the skills necessary for investigating and learning the science or mathematics. This is necessary for teachers to provide students with in-depth learning of science and mathematics content and processes. For example, a teacher with an understanding of the interconnected concepts of buoyancy and density is better able to guide students' learning during inquiry-based activities when students ask, "Why does the cork float and the marble sink?" In mathematics, a teacher who has a firm understanding of fractions would "hear a student's comment that 'the larger the number on the bottom, the smaller the fraction'" as being "true only when the numerator remains constant (1/5 is less than 1/3, but 3/5 is not less than 2/4)" and would be able to provide additional problem-solving experiences to help the student refine his or her understanding (Cohen & Ball, 1999, p. 8)

Immersion in Inquiry in Science and Problem Solving in Mathematics

Elaine, Teri, Kevin, and Shelly, mathematics teacher colleagues at Riverside School, were attending a seminar at a local university. As a prelude to a discussion on open-ended investigations, the teachers were presented with and asked to explore the following problem: How many 1 ft. × 1 ft. square floor tiles would you need to make a border on the floor around the edge of a rectangular room? The group began by trying to decide what the smallest room could be that would have a tile border as described. After some discussion of the meaning of "border," they agreed that a 3 ft. × 3 ft. room would be the smallest and that it would have one tile in the interior. The group proceeded to build a model of the situation and concluded that the border would require eight tiles. At this point, Teri suggested that they look at a room that was 7 ft. × 8 ft. (She had drawn a sketch of the tile border for a 7 ft. × 8 ft. room while the other three members of the group were determining the smallest case.) Kevin suggested that they subtract the area of a 6 ft. × 5 ft. rectangle from the area of the 7 ft. × 8 ft. rectangle because this difference would result in the number of tiles on the border of the 7 ft. × 8 ft. rectangle. He used Teri's diagram to explain this solution method to the members of the group.

The teachers continued to explore different cases and to make conjectures regarding the number of square tiles in the borders of rooms with different dimensions. After much discussion and exploration, Kevin suggested an approach that seemed to "work" for rooms of any dimension. They then tested the suggested generalization and concluded that it did indeed work for any case.

Immersion in inquiry in science or problem solving in mathematics is the structured opportunity to experience, firsthand, science or mathematics content and processes. By becoming a learner of the content, teachers broaden their own understanding and knowledge of the content that they

are addressing with their students. By learning through inquiry and problem solving—putting the principles of science or mathematics teaching and learning into practice and experiencing the processes for themselves—teachers are better prepared to implement the practices in their classrooms. The goal is to help teachers become competent in their content and reflective about how to best teach it. Immersion experiences are usually guided by knowledgeable and experienced facilitators with expertise in science or mathematics. The curriculum is designed specifically to highlight the processes of inquiry and mathematical problem-solving approaches to learning mathematics and science content.

Key Elements

KEY ELEMENTS FOR IMMERSION IN INQUIRY IN SCIENCE AND PROBLEM SOLVING IN MATHEMATICS

- **Immersion in an intensive learning experience.**
- **One goal is learning how students learn science and mathematics.**
- **Teachers' conceptions about science, mathematics, and teaching change as a result of these experiences.**

Immersion in an intensive learning experience. Teachers are immersed in an intensive experience in which they focus on learning science or mathematics and are able to pursue content in-depth. In science, they participate fully in the generation of investigable questions, plan and conduct investigations that allow them to make meaning out of the inquiry activities, collect and organize data, make predictions, and gain a broader view of the science concepts they are investigating. In mathematics, they "generate compelling questions, conduct investigations to make meaning out of mathematical activities, collect and organize data, make predictions, measure and graph, and gain a broader view of the mathematics concepts they are investigating" (Eisenhower National Clearinghouse, 1998, p. 11).

One goal is learning how students learn science and mathematics. One goal of these experiences is to engage teachers in firsthand learning of what they are expected to practice in their classrooms—guiding students through inquiry-based science or mathematical problem solving.

Teachers' conceptions about science, mathematics, and teaching change. One outcome from in-depth immersion in the processes of learning science and mathematics is a change in teachers' conceptions of the nature of science or mathematics learning and teaching. For example, as teachers begin to see science or mathematics teaching as less a matter of knowledge transfer and more an activity in which knowledge is generated through making sense of or understanding the content, they begin to see their own role as teacher

changing from a direct conveyor of knowledge to a guide helping students develop their own meaning from experiences. As Schmidt (2001) proposes, "A teacher's understanding and conception of subject matter is one of the major aspects that defines teacher quality. The key is that the conceptual problem-solving aspect, together with the attendant pedagogical approaches, must be embedded in real science content" (p. 162).

Implementation Requirement

Qualified facilitators. Guiding teachers through the inquiry process and solving challenging mathematical problems must be a specified goal of the immersion experience and one that is carried out by someone with expertise in content and process.

Long-term experiences. Immersion in science inquiry and mathematical problem solving require in-depth, over-time learning that cannot be accomplished in one-shot workshops.

Examples

PROMYS is an immersion-in-mathematics experience conducted by Boston University's mathematics department and the EDC. The program is designed to enhance problem solving and open-ended exploration in high school mathematics classrooms throughout Massachusetts through immersing teachers in adult-level mathematical explorations. According to the PROMYS Web site, "The program fosters new insights into the nature of mathematical investigations and participants practice the habits of mind that are at the core of creative mathematics. Academic year workshops help teachers translate the summer experience into fundamental change in their own classrooms."

The program includes three components: the six-week summer institute focuses on immersing high school teachers in mathematical ideas, five workshops throughout the academic year translate the teacher's learning into classroom experiences for students, and a second summer institute for engagement with more advanced mathematical ideas. During the summer immersion experiences, teachers work with counselors, graduate students, research mathematicians, and previous PROMYS teachers as they solve problem sets focused on number theory. The in-depth examination of individual problem sets is enhanced through weekly "problems sessions" at which PROMYS staff help participants understand themes and ideas that connect the problem sets and focuses them on the conceptual understandings and "big ideas."

A unique aspect of PROMYS for teachers is the parallel program for students. Each participating teacher is asked to recommend a high school student to participate in the PROMYS for student program. That program engages high school students in age-appropriate experiences similar to those of the teachers—exploration of "unusually challenging problems in number theory."

At the Exploratorium's Institute for Inquiry, the professional development is deeply rooted in the belief that human beings are natural inquirers and that inquiry is at the heart of all learning. Educators personally experience the process of learning science through inquiry to stimulate thinking about how to create classrooms that are supportive environments for children's inquiry. Scientists and other educators guide teachers through the inquiry process. As teachers engage in investigations, they develop a deeper understanding of science content and the inquiry process. They also work collaboratively with other teachers to explore the application of their new knowledge and skills in the classroom.

Commentary

Even with extensive coursework in their preservice programs, many teachers come to the teaching of science or mathematics without having had opportunities to engage in science inquiry or mathematical problem solving themselves. Immersion strategies can provide an opportunity to help teachers address this gap in their learning. Immersion experiences are beneficial, but they have their drawbacks as well. Teachers with limited time and programs with limited resources may not be able to afford the time required for in-depth investigation and may opt for shorter-term experiences with, for example, the student learning materials.

Another interesting issue is where immersion in science inquiry or problem solving in mathematics best fits into a teacher's learning sequence. For example, at the City College Workshop Center in New York (see Chapter 6), Hubert Dyasi uses immersion in science inquiry to initiate teachers into a new view of science. Others may choose immersion as a more in-depth enrichment, once teachers learn to use and are comfortable with a set of materials for their students. They then gain a better understanding of how to help students explore important ideas, follow their own lines of investigation, generate alternative solutions to problems, or all three. For example, teachers implementing standards-based mathematics programs such as Investigations or Everyday Math often experience the need to increase their own content knowledge through immersion experiences.

One additional issue related to immersion experiences is the critical need to directly connect teacher learning of science and mathematics to what is taught in the classroom. For example, although an elementary school teacher might personally benefit from learning calculus, unless there is an emphasis in the immersion experience to help teachers translate the

new knowledge into direct application in the classroom, the professional development aspect of the experience may be lost.

Resources

Education Development Center (EDC). Newton, MA (www.edc.org).

Exploratorium's Institute for Inquiry. San Francisco (www.exploratorium.edu/IFI).

PROMYS for Teachers, Boston University and Educational Development Center, Boston (math.bu.edu/people/promys).

WestEd and the WGBH Educational Foundation. (2003). *Teachers as learners: A multimedia kit for professional development in science and mathematics*. Thousand Oaks, CA: Corwin Press. (See Tape 4, Program 4, *Immersion in biotechnology, Biological Sciences Curriculum Study, Colorado Springs, CO;* Tape 3, Program 1, *Scientific inquiry, Institute for Inquiry at the Exploratorium, San Francisco;* Tape 4, Program 3, *Immersion in number theory, PROMYS, Boston University, Boston;* and Tape 2, Program 4, *Immersion in spatial reasoning, San Diego State University, San Diego, CA.*)

Immersion in the World of Scientists and Mathematicians

As part of an eight-week immersion experience coordinated by the Department of Energy's Teacher Research Associates (TRAC) program in the 1990s, at the Superconducting Super Collider Laboratory (SSCL), Robert, a high school physics teacher, participated in a research study. He measured properties of scintillating tiles and fibers to understand the production and transportation of light in the tile and fiber assemblies for the Solenoidal Detector Collaboration (SDC) calorimeter. These data were used to understand how to optimize the light output of these assemblies and how to design a calibration system for the SDC calorimeter. His work included exciting tiles with an ultraviolet laser and measuring the light output with a photomultiplier tube under various conditions, measuring the transmission properties of samples of scintillators using a spectrophotometer, measuring the spectrum of the scintillation light in various samples using a fluorescence detector, and using a cosmic ray test station to study the response of a tower constructed from the tile and fiber assemblies.

At the end of his research experience, Robert designed a transfer plan identifying ways he wanted to share his experiences with other physics teachers; he participated in workshops and attended presentations at which he shared his research, in a paper titled "Correlation of Photoluminescence Spectra of Plastic Scintillator Tiles and Wavelength-Shifting Fibers With Light Output From Tile-Fiber Combinations."

The vast majority of science and mathematics teachers have never had an opportunity to actually "do" science or mathematics in a real-world setting. This situation perpetuates certain myths about the nature of science

and mathematics because most teachers do not have practical experience in the fields they are teaching. Immersion in the world of scientists and mathematicians is one way to resolve this and provides an opportunity for teachers to strengthen their knowledge base in content areas by becoming active participants in a mathematics or scientific community.

This strategy differs from immersion described previously in one significant aspect—frequently, the setting for immersion in the world of scientists and mathematicians is a research environment, such as a scientific laboratory or a mathematics research group or a museum research department. In other words, teachers are immersed in scientists' or mathematicians' environments and teachers join them in their work and fully participate in research activities. The purpose of this approach to immersion is for teachers to learn science and mathematics content; to learn elements of the research process, such as designing experiments, creating mathematical models, and collecting, analyzing, and synthesizing data; and to develop a broader and increased understanding of the scientific and mathematics approaches to building knowledge and solving problems.

Key Elements

The experiences are designed as mentored research opportunities for teachers, as apprentice researchers, to learn the content, process, culture, and ethos of scientific or mathematics research and development work. Teachers benefit from authentic experiences outside of the classroom. Most teachers find that becoming an active member of a research team allows them to explore and develop their role as leader, equal partner, and contributing member of an interdisciplinary team, and it provides them with the opportunity to share their experiences beyond both the laboratory and classroom (e.g., at national conferences). For example, programs such as the National Aeronautics and Space Administration (NASA) immersion projects develop online

KEY ELEMENTS FOR IMMERSION IN THE WORLD OF SCIENTISTS AND MATHEMATICIANS

- **The experiences are designed as mentored research opportunities for teachers, as apprentice researchers, to learn the content, process, culture, and ethos of scientific or mathematics research and development work.**
- **Teachers attend lectures and seminars and read materials on the science or mathematics topics related to the research.**
- **Teachers actively participate as members of research teams, which include scientists or mathematicians or university faculty.**
- **The program includes planning for how to connect learning to teachers' classrooms.**
- **There are opportunities for follow-through with implementation and dissemination at local, regional, and national levels, as well as opportunities for ongoing communication.**
- **Teachers document their learning and reflect on their experiences.**

communities to enable teachers to stay involved electronically once they return to their classrooms.

Teachers attend lectures and seminars and read materials on the science or mathematics topics related to the research. As part of their immersion in the science or mathematics community, teachers participate in activities outside of their research that enhance their experiences and contribute to their knowledge base.

Teachers actively participate as members of research teams, which include scientists or mathematicians or university faculty. As part of their research experience, teachers contribute to the ongoing work of the research team by presenting oral reports on what they are learning, critically reviewing their own and others' work, and participating in team meetings.

The program includes planning for how to connect learning to teachers' classrooms. Teachers create action plans or instructional activities to transfer what they have learned to their classrooms. Although the main objective of immersion experiences is the professional development of teachers, one outcome is that as teachers obtain greater content and process knowledge, understanding of the research community, and experience in "being" a scientist or mathematician they are better able to devise methods for sharing this learning with their students.

There are opportunities for follow-through with implementation and dissemination at local, regional, and national levels, as well as opportunities for ongoing communication. Most immersion programs encourage all members of research teams to both individually and jointly present their findings and their experiences at meetings and in journal articles. Programs also encourage research team members to maintain communication with each other, either through in-person meetings or electronically, view their scientist or mathematician mentors as resources, and, in some cases, invite them to visit classrooms throughout the school year. Other programs offer "class reunions" at regional or national conferences, newsletters, and electronic networks for "graduates."

Teachers document their learning and reflect on their experiences. Many immersion programs incorporate keeping a journal or writing about the immersion experience. Teachers find that writing about their experiences as they progress over time helps deepen the experience itself and helps them recognize that they have "become" a scientist or mathematician. The gaining of this perspective during the immersion program encourages teachers to return to the classroom with a different view of themselves.

Implementation Requirements

Funding. Because this is a "one teacher at a time" professional development experience, it can be expensive.

Access. Teachers need access to a research setting in which scientists and mathematicians are willing and able to serve as mentors.

Shared expectations and goals. All involved in the immersion experience need to have open, frequent communication and establish shared goals and expectations for the assignments and experiences of the teachers.

Resources and support. Teachers need support from their school administrators to return to the classroom and use what they have learned.

Examples

Perhaps the single largest professional development program that enables teachers and scientists to work together is the Teacher Research Associates (TRAC) program located at many of the nation's 28 National Energy Laboratories. One TRAC location is Brookhaven National Laboratory (BNL) in New York. This TRAC program is conducted in close cooperation with New York University (NYU). It began in response to a needs assessment of New York City teachers indicating that 90% of those surveyed felt uncomfortable with their science background, with many interested in personal interaction with a scientist in a laboratory setting. Teachers participate as interns at Brookhaven as part of a master's program for inservice teachers at NYU. As Leonhardt and Fraser-Abder (1996) state,

> Teacher interns arrive at BNL during the second week of July and quickly immerse themselves in their research. The interns perform laboratory and library research under the supervision of their scientist/advisors. Throughout the experience interns are treated as members of the scientific community. They have access to BNL resources and are encouraged to request assistance as needed and perform research as assigned. The interns live on-site for the duration of the internship. They participate in all programmatic and social activities, including weekly lunchtime discussions that focus on transferring the research experience to the classroom. The teachers form a cohesive group and share their laboratory successes, difficulties, and classroom strategies. Toward the end of their internships, teachers apply for small grants to support the transfer of their lab experience into their classrooms. At this time teachers also begin making preliminary plans to have either their scientist/advisor visit their

> classes during the fall semester or to have their classes visit BNL. (p. 33)

The University Research Expeditions Program (UREP) of the University of California, Davis, offers opportunities for teachers to work with faculty in the sciences and social sciences on their current field research projects. UREP subsidizes teachers' field expeditions and provides campus workshops at which teachers develop curriculum based on the research performed on an expedition. The mission of the program is to provide teachers with the opportunity to engage in real science so that they can go back to their classrooms and perform similar activities, to teach the process of science rather than accumulating facts, and to open up channels of communication between scientists and educators. One teacher who conducted a wetlands research project in Belize summarized her experiences as follows (WestEd, 1996):

> I've seen teachers make incredible leaps in terms of their confidence. Even if we've had training in science, we've rarely had opportunities to participate in real scientific research. What we do when we are isolated in classrooms is very different than what happens in universities, and UREP gives us a real understanding of how a scientist approaches a problem. (p. 9)

Commentary

Immersion experiences can be extremely rewarding for teachers and result in changes in classroom practices. There are, however, several "pitfalls." First, scientists and mathematicians sometimes prefer "helpers" who already have degrees in science or mathematics; those who fill the bill are commonly high school teachers. This somewhat limits the pool of teachers who can benefit from this kind of experience. There are, however, locations and assignments that welcome teachers with less experience.

Second is the question of the degree to which teachers are able to translate important aspects of their internship experience into the classroom. Staff at one program confronted this problem when past participants told them that, when they returned to their schools, they were frustrated by a lack of equipment and by colleagues and administrators who were unwilling to make changes in the school setting to accommodate an improved science program. Program sponsors addressed the problem by limiting admission to teachers whose administrators promised to provide support to maximize the teachers' effectiveness when they returned to the classroom. Other programs include partnership agreements with school districts or individual schools to implement changes that would use the teachers' research experience during the academic year. Many of these programs also provide structures for continued contact and support for teachers with their

mentors, project staff, and fellow participants. Although imposing these types of contracts and partnership agreements on teachers and their administrators addresses the problems identified, it also limits the number of teachers who are able to participate in research opportunities to those with local support.

Third is the issue of whether teachers actually need to bring something back to the classroom other than a renewed interest in and commitment to their field and an increased understanding of the content. Some believe that it is enough for teachers to develop this interest and knowledge and that this will lead them to share their enthusiasm and new knowledge with students. Others believe that it is important to incorporate into the immersion experience strategic plans for implementing new learning in the classroom.

A fourth issue concerns the relationship between scientists and mathematicians and teachers in the research environment. At best, it is collegial, and the scientist or mathematician has sufficient time to work with the teacher to involve him or her in the research process. There is the danger, however, that teachers will be given repetitive tasks with little explanation or that they will be asked to read and attend lectures with advanced scientific or mathematics content and might then try to pass on the knowledge in a similar manner to their students. This problem can be addressed through careful orientation of mentors and guidance in selecting teacher research assignments. It arises less frequently with internship programs connected with museums, where teachers work closely with museum experts in developing exhibits, planetarium programs, or other activities for the general public. Because the main goal of museums is education, museum staff members are frequently more effective coaches for how to translate learning to the classroom than are many scientists and mathematicians.

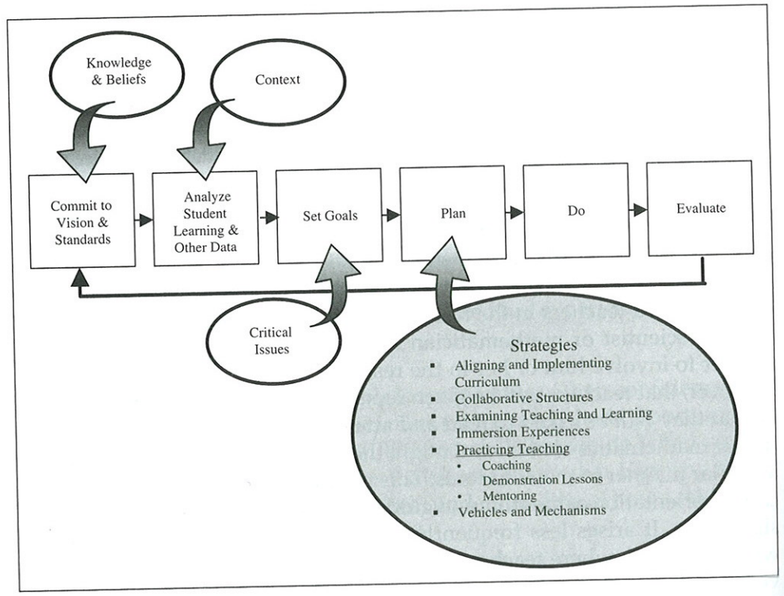
Finally, the cost of providing this strategy for teachers has led many to dismiss it as a viable opportunity for teacher professional development. Many believe that the money can be better spent in ways that reach more teachers. Some corporations and businesses are working with universities and research facilities to create sponsored internships for teachers. Many provide money for scholarships to purchase equipment and supplies for the classroom, pay for fellows' substitute teachers when they attend conferences and inservice workshops, and reproduce the materials they might develop during the internship (e.g., videos or software). Sponsored internships can help defray the costs associated with this professional learning strategy.

Resources

Teacher Research Associates (TRAC) program, Brookhaven National Laboratory, New York (www.bnl.gov/dtra).

University Research Expeditions Program (UREP), University of California, Davis (www.urep.ucdavis.edu).

Figure 5.6. Strategies for Professional Learning: Practicing Teaching



PRACTICING TEACHING

Many professionals use practice sessions as a means to enhance their knowledge, skills, and performance. For example, musicians, lawyers, athletes, and medical personnel are called on to practice through demonstration and gain tips and feedback from colleagues and coaches. The three professional learning strategies in this section—coaching, demonstration lessons, and mentoring—are the strategies educators use as "practice sessions." (See Figure 5.6.) The strategies emphasize practicing teaching in classrooms with the purpose of improving science and mathematics teaching and learning. They are used to induct new teachers or to support the use of new practices by experienced teachers. Coaching and mentoring are usually conducted in one-on-one situations—one coach or mentor working with one teacher; the purpose is to enhance the knowledge, learning, and practice of one teacher. In demonstration lessons, groups of teachers work together observing and learning from demonstration lessons. The purpose is to enhance the performance of many teachers.

Underlying Assumptions

Teachers are competent professionals whose experience, expertise, and observations are valuable sources of knowledge, skill development, and inspiration for other teachers. This is a critical assumption to which professional developers must subscribe to consider using these strategies in their professional development programs. Some people believe that what science and mathematics teachers need is assistance from an outside expert. The critical and specialized knowledge that experienced teachers have—pedagogical content knowledge (Shulman, 1986)—is not acknowledged as worth sharing. It is this very knowledge, however, that helps teachers understand what their students need, how they come to understand certain concepts and principles of the content, and what they need to increase that understanding.

Stepping outside of the teaching moment is a valuable way of examining teaching and learning. When teachers are engaged in interactions with students in their classrooms, they are constantly making decisions, gauging the appropriate next steps, and anticipating questions to ask of students. Being in the "teaching moment" does not provide an opportunity for teachers to reflect on their teaching moves or students' interactions. It is a valuable experience for teachers to observe others teaching with the explicit purpose of examining teaching strategies and questioning, listening to student discussions, and seeing a lesson in action.

When teachers objectively observe positive learning results with students, they are more likely to sustain and implement changes in their own teaching. For most teachers it is the enhanced learning by students that leads to commitment to teaching in new ways or using a new set of instructional materials. Observing others teach a lesson with students allows teachers to carefully attend to the questions students ask, the struggles they have with understanding the content, and the ways in which they interact with each other and the demonstration teacher. When student learning is evident, observing teachers are more likely to see the value of the strategies used and be willing to try them in their own classrooms.

Translating new learning into practice is best accomplished in collaboration rather than in isolation. Rather than participate in professional development and simply return to the classroom to implement that new learning, these strategies provide an opportunity for teacher practice, reflection, and continued improvement. Teachers receive support to try new practices in the classroom, are observed and receive critical feedback, and engage in reflective thinking concerning their teaching and their students learning. Research continually shows that changes are more likely to be sustained when there is continuous support for adapting teaching practices than when teachers

return to their classrooms without support (Cohen & Hill, 1998; Garet et al., 1999).

The school culture supports and encourages continuous improvement for all teachers. Both new and experienced teachers need opportunities to continue learning and growing. Effective schools routinely provide opportunities for teachers to learn in collegial and collaborative ways. New teachers have access to ongoing support as they learn to manage classrooms and enhance student learning. More experienced teachers also have opportunities for continual growth, moving into leadership roles within the school.

Coaching

Reviewing the schedule for Thursday, Renata sees that Julia, her teacher leader, will come in as usual for a weekly observation during her reading lesson. She reminds herself to review her action plan before their meeting and to make sure that Carol, the paraprofessional, has been scheduled to cover her classroom while she meets with Julia after the observation.

When they meet to talk about a lesson, they focus on Renata's action plan—the one she made for herself—and talk about how it played out in the lesson. One thing they don't talk about is how to "fix" the lesson. Referring to specific things she observes, Julia often asks, "Why do you think that happened?" Sometimes they agree, sometimes they don't. But if they don't, they explore further, and that's when it's really the most fun. Julia also recommends some articles about questioning strategies that she and Renata could read and discuss. In fact, Renata had built one of those new strategies into the lesson Julia would see on Thursday. (WestEd, 2000)

Coaching is a professional development strategy that provides one-on-one learning opportunities for teachers focused on improving science and mathematics teaching by reflecting on one's own and/or another's practice. It takes advantage of the knowledge and skills of experienced teachers, giving them and those with less experience opportunities to learn from each other.

Over the years, particular forms of coaching have emerged with different purposes and correspondingly different techniques, as suggested by the labels of *technical coaching, collegial coaching, challenge coaching, team coaching, cognitive coaching, linguistic coaching,* and *peer coaching* (see the Resources section). All incorporate a traditional supervisory model focused on classroom observations and use a preconference-observation-postconference cycle.

More recently, coaching as a form of professional learning has shifted to focus less on the supervisory model and more toward collaborative, peer learning. In this model, the goal of coaching is to enhance the learning of both the coach and the teacher being coached and the role is characterized by facilitation of learning and not on evaluation of practice. Coaching is

most effective when the coach is able to match the coaching style with the level of structure needed by the teacher being coached. For example, teachers who are just learning a new curriculum model have a high need for structure. In these cases, the coach may use a *direct informational style of coaching* where the coach directs the conversation by providing pertinent information. When the teacher has a low need for structure and is simply needing to "talk through" which of several strategies he or she might use in the classroom, a *nondirect style* of coaching is most appropriate. When using a nondirect style, coaches listen, clarify, and encourage the other teacher to present their ideas. A *collaborative style* of coaching is one where the coach and the teacher engage in a collegial exchange of ideas and coplan/problem solve. When teachers have a moderate need for structure, that is, they have some ideas and some challenges to work through, this approach works best.

The purpose of most coaching is to enhance the use of specific curriculum, instructional materials, or teaching strategies. For example, many school districts combine the use of coaching with science or mathematics curriculum implementation (see description of Curriculum Implementation in this chapter). Teachers new to the science or mathematics curriculum have a coach who helps them understand the conceptual ideas in the lessons and who provides feedback on their teaching. Coaching is a teacher-to-teacher professional learning strategy that helps teachers embed new learning into their classroom practices.

Key Elements

KEY ELEMENTS OF COACHING

- **Teachers focus on learning or improvement.**
- **Mechanisms for practice and feedback are critical.**
- **Coaching requires that teachers have opportunities for interaction.**

Teachers focus on learning or improvement. Coaching is most successful when teachers agree that they will work on examining particular teaching techniques, student interactions, perplexing problems, or learning strategies. Sometimes, this is as focused as tallying the number and kinds of questions teachers ask of different students to understand any gender or cultural biases, which is of great importance in teaching science and mathematics. Other times, it is more general, such as techniques used to manage materials. Although being supportive in general is an important role for coaches, when coaches observe in classrooms they need a predetermined focus that they agree on with the teacher being observed.

Mechanisms for practice and feedback are critical. For classroom observations, preconferences typically are opportunities for the coach and the teacher

being observed to agree on the focus and set ground rules about the kind of feedback that will be helpful. Postconferences, then, are guided by these agreements. Different approaches to coaching suggest different forms of sharing and feedback, some structured by classroom observation instruments and others as open as sharing detailed, but unstructured, observations of the flow of the lesson. Likewise, forms of feedback vary from simple description to particular forms of questioning. Critical feedback provided in a nonthreatening manner is essential in all reflective sessions. Teachers often are not experienced in challenging each other's ideas, and in a coaching relationship it is essential that both participants be willing to be a "critical friend" (Costa & Kallick, 1993).

Coaching requires that teachers have opportunities for interaction. It almost goes without saying that for coaching to be successful, teachers need opportunities to interact with each other. For example, just having time for classroom observations without protected time to talk before and after defeats the purpose of careful and shared examination and understanding of teaching practice. Although a less experienced teacher may pick up some tips from sitting in on a lesson taught by a more experienced teacher, a follow-up discussion of what was done, why, and with what impact is critical to understanding teaching.

Implementation Requirements

A climate of trust, collegiality, and continuous growth. Coaching relationships are strengthened by a willingness to take risks and learn from failures, acknowledgment of strengths and weaknesses and desire to build improvement strategies on both, welcoming the role of a critical friend (Costa & Kallick, 1993), and accepting learning as a continuous process.

Long-term commitment to interaction. Coaching requires building trust, which takes time. Teachers in coaching relationships also must build an understanding about what each knows about teaching, learning, and content. As this understanding increases, they become more helpful to each other. This can happen only if their interaction occurs with some regularity, so that suggestions and insights can be tried and reflections on their impact shared.

Skill building in coaching. Coaching requires special skills in communication (e.g., clarifying, paraphrasing, conflict management, and listening), observation, and giving feedback. Training programs are available for this purpose (see the Association for Supervision and Curriculum Development and the National Staff Development Council in the Resources section and Learning Innovations at WestEd). Coaches need their own professional development to learn how best to translate their own knowledge and experience to others. Coaches also benefit from understanding principles of adult learning and the change process (see Chapter 2). In addition, the more a coach understands about the content being taught and knows from experience how students learn it (and how to teach it), the better. Good coaches help teachers become more reflective in their practice and better inquirers into problems and dilemmas of teaching. They can be of much greater assistance when they know the specific science or mathematics content being taught by the teachers with whom they are working.

Administrative support. Coaching requires that teachers form ongoing relationships. Administrators must recognize and articulate the importance of coaching relationships and activities, allocate or reallocate time in ways that pairs have time to observe each other and work together, and nurture and support the building of a learning community in the school that has these teacher partnerships at its core (Garmston, 1987; Showers & Joyce, 1996).

Examples

In school districts throughout the United States, Critical Friends Groups (CFGs) are working with teachers to increase student learning and enhance collegial interactions among school faculty. CFGs—teachers from schools who want to develop leadership and coaching skills—attend professional development and training conducted by the National School Reform Faculty, located, since 2000, at Harmony School Education Center in Bloomington, Indiana. The training program is "practitioner-driven and highly collaborative" and trains coaches to help their schools "identify learning goals that make sense in their schools, look reflectively at practices intended to achieve those goals, and collaboratively examine teacher and student work in order to meet their objectives" (Dunne, Nave, & Lewis, 2000). Coaches facilitate several different professional learning strategies to move teachers and schools toward collaborative learning communities, including examining student work, study groups, peer observation, and helping teachers build portfolios. By 2000 in the United States, 1,000 coaches in 700 schools had attended CFG professional training sessions.

During 1996–1998, a study was conducted of the CFG training and the impact of CFGs in their schools. The researchers found that the most frequently cited reasons for the effectiveness of the professional development and training were that it is ongoing, it is practice based, and it is implemented in their own schools (Dunne et al., 2000). The researchers also found that seemingly long-lasting changes were occurring in CFG classrooms and schools. For example, CFG classrooms had shifted from more teacher-centered environments to student-centered ones focused on instruction aimed only at learning and not at passing standardized tests. They also reported that teachers in CFG schools were more "thoughtful about the connections among curriculum, assessment and pedagogy" (Dunne et al.,